Trade-off-based Decision Methodology for Adopting Cloud-based Services in an Organization

Dissertation Submitted to the Faculty of Business,
Economics and Informatics
of the University of Zurich

To Obtain the Degree of
Doktorin der Wissenschaften, Dr. Sc.
(Corresponds to Doctor of Science, PhD)

Presented by
Radhika Garg
from India

Approved in October 2016

At the request of
Prof. Dr. Burkhard Stiller
Prof. Dr. Joan Serrat

University of Zurich[UZH]

The Faculty of Business, Economics and Informatics of the University of Zurich hereby authorizes the printing of this dissertation, without indicating an opinion of the views expressed in the work.

Zurich, October 26 , 2016

Chairwoman of the Doctoral Board: Prof. Dr. Elaine M. Huang

Abstract

PLAYERS such as Google, Amazon, or Microsoft offer a plethora of alternative cloud-based services. The decision to move from legacy IT infrastructure or existing cloud-based services to another cloud-based solution for fulfilling new or existing IT requirements in an optimized manner for any organization is not a trivial process. Such a decision is affected not only by different alternative solutions, but also by contradictory or mutually dependent influencing criteria or factors. Therefore, decisions to adopt cloud-based services or any new technology better follow a quantified trade-offs based methodology.

Today, the decision-making method in organizations for the selection of cloud-based solutions is an ad-hoc process that is solely based on the market reputation of the Cloud Service Provider and past experiences of IT (Information Technology) decision makers within an organization. Even though, these are important factors in such a process, they are by far not sufficient as such decisions do not have an objective and quantitative basis. Such a decision-making process of selecting the best alternative falls within the category of Multiple Criteria Decision Analysis (MCDA). One of the MCDA algorithm namely Analytical Hierarchy Process (AHP) has been used to rank cloud-based services by structuring relevant factors in a hierarchy. However, the problem is that this approach still lacks a holistic view of integrated relevant factors from technical, economical, and organizational domains and their interrelations forming a complex network of many inter-dependent or even conflicting factors.

TrAdeCIS is evaluated with respect to four use cases that involved decisions of adopting cloud-based services of organizations who participated in exploratory research. These evaluations varied in complexity of the decision models due to the inclusion of different relevant factors, their interrelations, and alternatives. It concluded that TrAdeCIS can be applied to model and make such quantitative decisions. Performance evaluation of TrAdeCIS calculated the execution time of ranking 100 alternatives using 100 technical criteria, and 100 economical and organization criteria (which is the upper limit of factors based on the exploratory research) as fast as below 20 ms. This is achieved an optimized implementation of TrAdeCIS to ensure that results obtained are not outdated due to dynamically changing input in performance values of an alternative. An application of TrAdeCIS, for extensibility and generalization evaluations, to the decision of choosing the best technology by train operating companies to improve both voice and data coverage on-board of trains proves that TrAdeCIS is even valid for a decision of adopting any new technology in an organization. Hence this thesis concludes that the only

requirement for a general applicability of TrAdeCIS is that the decision must involve multiple alternative solutions, which have to be evaluated for multiple criteria.

Hence, this thesis investigates the following three aspects that provide for seamless unification of multiple alternatives, relevant factors, and their interrelations under a single developed system for decision making of adopting a new technology, specifically Cloud Computing. Firstly, exploratory research led to the development of a new structured taxonomy consisting of 102 factors and their interrelations. This coherent taxonomy forms the basis for evaluating the performance of alternative cloud-based services from all relevant perspectives. Secondly, a Trade-offs Based Methodology of Adopting Cloud-based Services (TrAdeCIS) is designed and implemented prototypically as a Web-based platform for ranking alternatives. This performs and supports quantified trade-offs-based decisions for selecting the best technical and at a trade-off of business value, if the ranking of alternatives from technical and business perspective is not the same. This platform also facilitates demonstrations and use-case based evaluations of TrAdeCIS. Thirdly, a predictive Impact Analysis Methodology for Cloud-based Services (IAMCIS) is developed to measure the impact of adopting the top ranked alternative as per TrAdeCIS. This leads to the identification of potential risks associated to any failure of services.

Kurzfassung

Google, Amazon oder Microsoft bieten eine Vielzahl von Cloud-based Services an. Die Entscheidung einer Organization mit einer althergebrachten IT-Infrastruktur oder einem bestehenden Cloud-basierten Dienst zu einer anderen Cloud-basierten Lösung zu wechseln, um neue oder existierende IT-Anforderungen optimal zu erfüllen, ist kein trivialer Prozess. Nicht nur verschiedene Lösungen beeinflussen eine objektive Entscheidungsfindung, sondern auch widersprüchliche oder gemeinsame Beeinflussungskriterien oder Faktoren spielen eine wichtige Rolle. Daher ist es erstrebenswert, einer quantifizierten Method zu folgen, die einer Lösung der Zielkonflikte Rechnung trägt.

Heutzutage basieren derartige Entscheidungsfindungsmethoden in Organisationen typischerweise auf einem ad-hoc Prozess. Dieser Prozess involviert Marktreputation der einzelnen Cloud-Diensteerbringer und vorangegangene Erfahrungen der Entscheidungsträger innerhalb der Organisation. Obwohl dieses wichtige Faktoren darstellen, sind sie nicht ausreichend, da sie keine objektive und quantitative Basis aufweisen. Ein Entscheidungsprozess zur Auswahl einer besten Alternative fällt in die Kategorie der Entscheidungsanalyse mittels mehrfacher Kriterien, Multiple Criteria Decision Analysis (MCDA), welche durch verschiedene Algorithmen realisierbar ist. Der sogenannte Analytische Hierarchieprozess (Analytical Hierarchy Process, AHP) definiert einen solchen Ansatz, um Cloud-basierte Dienste hinsichtlich relevanter Faktoren strukturiert zu bewerten. Dieses Ansatz vernachlässigt allerdings ein ganzheitliches Konzept und somit die Integration relevanter Faktoren aus technischen, ökonomischen und organisatorischen Bereichen, sowie die daraus resultierenden Wechselbeziehungen in einem komplexen Netzwerk.

Daher untersucht die vorliegende Dissertation die folgenden drei Aspekte, um eine nahtlose Vereinigung verschiedener Alternativen, relevanter Faktoren und ihrer Wechselbeziehungen in einem einzigen System zur Entscheidungsfindung für die Einführung einer neuen Technologie, speziell des Cloud Computing, zu finden. Zuerst führte eine explorative Studie zur neuen Entwicklung einer strukturellen Taxonomie, welche aus 102 Faktoren und ihren Wechselbeziehungen besteht. Diese Taxonomie bildet die Basis für die Bewertung der Leistung alternativer Cloud-basierter Dienste hinsichtlich aller relevanten Perspektiven. Zweitens wurde Trade-offs Based Methodology of Adopting Cloud-based Service (TrAdeCIS) entwickelt und in einem Prototyp implementiert. Der resultierende Prototyp stellt eine Web-basierte Plattform

zum Bewerten der Alternativen dar. Diese ermöglicht auch Evaluationen basierend auf Demonstrationen und Anwendungsf llen. Drittens wurde eine vorausschauende Impact Anaylsis Methodology for Cloud-based Services (IAMCIS) entwickelt, um den Einfluß der Anwendung zu messen, die von TrAdeCIS am höchsten bewertet wurde. Dies ermöglicht die Identifikation von potentiellen Risiken eines Fehlers von Dienstes.

TrAdeCIS wird mittels vier Anwendungsf lle evaluiert, die in die Entscheidungsfindung zur bernahme eines Cloud-basierten Dienstes innerhalb einer Organizationen mit einbezogen wurden. Die Evaluationen variieren in der Komplexität der Entscheidungsmodule, indem verschiedene relevante Faktoren, ihren Beziehungen zueinander und der Alternativen mit einbezogen wurden. Es stellte sich wie gew nscht heraus, daß TrAdeCIS angewendet werden kann, um quantitative Entscheidungen zu modellieren und zu berechnen. Eine Leistungsevaluation für TrAdeCIS hat gezeigt, daß unter 20 ms Zeit Sekunden benötigt werden, um 100 Alternativen unter der Verwendung von 100 technischen, 100 ökonomischen und organisatorischen Kriterien einzustufen. Diese Anzahl von Kriterien zeichnete sich als praktisch oberstes Limit für die Faktorenanzahl aus der durchgeführten Studie ab. Diese Ausführungszeit wird durch eine optimierte Implementierung von TrAdeCIS erreicht, weil erzielte Resultate nicht durch dynamische Eingabeänderungen der Leistungskennzahlen der Alternativen veralten. TrAdeCIS wurde zudem erfolgreich zur Entscheidungsfindung für eine Kommunikationst Technologie alternative angewendet, um durch diese an Bord von Zügen die Datenübermittlung (Sprache und Daten) zu optimieren. Daher kommt die vorliegende Dissertation zum Schluß, daß die einzig relevante Anforderung für die allgemeine Anwendbarkeit von TrAdeCIS die Einbeziehung verschiedener, vorab bestimmter alternativer Lösungen ist, welche bezüglich verschiedener Kriterien bewertet werden müssen.

Contents

1
Introduction

TECHNOLOGY advances in the last decade in the field of Cloud Computing has tremendously increased the relevance of cloud-based services in information technology, education, marketing, finance, banking, and telecommunications. Most common uses of such services include test and development of applications, file storage, big data analytics, disaster recovery, and backup.

1.1 Cloud-based Services

Traditional IT (Information Technology) aligns resources according to applications in order to fulfill business requirements. Each application has its own dedicated infrastructure and data storage [90]. Dedicated backup and recovery solutions are also deployed for data protection and continuity of business operations. As an alternative, Cloud Computing (CC) has recently emerged as a paradigm offering its users the flexibility of scaling their computing resource usage without the concern of over or under-provisioning [7]. CC is the result of evolution and embracement of various technologies consisting of Virtualization (separating physical devises into one or more virtual devices) [54], Service-oriented Architecture (based on loosely coupled independent services) [30], and Utility Computing (which charges the user based on the usage instead of a fixed rate) [80]. CC encapsulates hardware and system software that are used to deliver application as services over the Internet. The major benefits of cloud-based services include pay-as-you-go model, on-demand scalability, business agility, and increase in economies of scale [7]. However, there also exists disadvantages in terms of security, privacy risk, or vendor-lock in [17].

Depending on the service provided virtually, three fundamental and most commonly used service models namely Infrastructure-as-a-Service (IaaS), Software-as-a-Service (SaaS), and Platform-as-a-Service (PaaS) for CC are identified by National Institute of Standards and Technology [79]. Even though adoption of cloud-based services is gaining a momentum, it still lacks a systematic guidance for the decision of adopting an appropriate service and deployment model (*e.g.,* public cloud, private cloud, or hybrid cloud). This decision should be based on requirements of an organization, and performance of different available alternatives. For example, if an organization has strict rules with respect to security and control over its applications and data, then private cloud is the most appropriate deployment model as it will give an opportunity to build infrastructure using their own servers and within their own network boundaries.

However, current decision processes of adopting an appropriate cloud-based service in an organization are based on ad-hoc inputs, or reputation of the cloud provider, and are not quantifiable [134]. In addition, with the growth in number of Cloud offerings (variation in performance levels at different associated cost) by different Cloud Service Providers (CSP), it has become increasingly difficult for potential Cloud customers to decide, which provider can fulfill their expectations fully. Therefore, a decision method is needed that can objectively rank different available alternatives based on their performance, goals, and priorities of an organization.

1.2 Decision to Adopt a New Technology

The decision to adopt any new technology is multi-faceted as it is influenced by numerous factors from multiple domains. Multiple Criteria Decision Analysis (MCDA) focusses on the selection of best alternative, when all relevant influencing factors are considered simultaneously. This area of decision-making, has attracted the interest of many researchers and is still highly debated as there are many MCDA methods, which would yield different ranking of alternatives, when they are applied on exactly the same input data [120]. In other words, the selection of an appropriate MCDA algorithm that can model these factors, their interrelations, and performance values of alternatives correctly is crucial to the selection of the best alternative. In the past, the MCDA algorithm of Analytical Hierarchy Process (AHP) has been used to rank cloud-based services by structuring the relevant factors or requirements in a hierarchy [46]. However, AHP only allows modeling of hierarchical relations, whereas more complex interrelations between factors might exist. Also, a lack of concretely identified objectives, policies, requirements or demands of organization, and uncertainty in the performance levels of these alternatives can lead to organizations not using any formal model for decision-making.

However, ad-hoc decisions are difficult to trace and correlate empirically. Also, if a wrong decision is made, the consequences of adopting an incorrect (not optimal) alternative by the organization can be multi-fold, depending on the mismatch between expectations or needs and performance of this alternative after its adoption. Therefore, evidence-based and quantified decision making have been attributed to increased productivity, reduced risks, cost reduction, improved financial performance, and increased transparency [52]. Influence of factors from multiple domains on the adoption decision is true for a wide array of technology such as:

Cloud-based Services are influenced by their technical performance, associated economical returns, and organizational impact [45].

Deployment of Internet on Train is influenced by multiple criteria from technical and economical perspectives to select the best on-board deployment option for on-train cellular connectivity [89]. Different alternatives of providing connectivity on the train can include Wifi, Wideband repeater, or IP (Internet Protocol) data access point.

Network Function Virtualization (NFV) includes virtualizing network functions such as load balancers, firewalls, or intrusion detection devices by moving them to the cloud. This will transform dedicated hardware platforms to software functions virtualized on independent hardware, and then to software functions operating in open, automated, dynamic, and scalable cloud environments. A migration to clouds can help operators to improve quality and cost of the services delivered to customers. However, the decision to select the best suitable cloud provider, service models, and deployment models is complex. This is because of the presence of multiple interdependent and contradictory technical, economical, legal and regulative requirements on one hand, and multiple available alternatives, on the other hand [85].

Therefore the decision to adopt any technology in an organization is a challenging task due to following reasons:

1. The decision maker has to take into account, the presence of **various alternative solutions**. For example, for selecting

an appropriate cloud-based service, the decision maker has options in terms of several CSPs and a plethora of service packages offered by each of the CSPs. Therefore, the decision maker has to make a successful decision that would in turn mean that the selected alternative matches the expected performance levels in the optimal manner as compared to all other alternatives.

2. The decision of adopting or not any new technology is influenced by **numerous factors** or requirements [119], [46]. These factors can be interrelated and/or contradictory, which in-turn might need the establishment of trade-offs. For example, scalability and cost are mutually contradictory factors with respect to cloud-based services. In other words, if the goal of an organization is to gain more computing power for peak loads, scalable resources would be required from CSP. However, this would lead at the same time to higher associated cost.

3. Based on requirements and goals of an organization, **factors can have different priorities** or relevance [25]. For example, for business critical applications, security, availability, and business continuity will be higher in priority as compared to cost incurred or energy efficiency of the deployed service. These priority values will be considered as weightage associated to each factor that influences the decision.

4. Also, these **requirements can be both quantitative and qualitative** in nature [119]. For example cost, availability, throughput, scalability are quantitative factors, with respect to cloud-based services. But there are also qualitative factors, like location, of stored data or supported standards [41], that influence such a decision. Therefore, it is crucial to rank or measure the performance of alternatives accurately for both of these categories of factors.

The existing research work in the domain of decision making for adopting a new technology is very narrow in its focus, and it does not look into the problem from all relevant facets. Some of these approaches look into the elicitation of requirements or relevant factors [134] or focus on decision making of predefined and limited number of factors [82], while others focus only on cost effectiveness of the adopted solution [123]. Therefore, a decision methodology for selecting the best available alternative is required, which can make a quantitative decision (a) based on different factors and performance of all alternatives per factor, (b) can model and include the priorities and interrelations of relevant factors, and (c) can support trade-offs for mutually conflicting factors. In addition, when service(s) become(s) unavailable due to a technical failure or disaster, performing an impact analysis of the(se) service(s) helps to determine appropriate recovery objectives and provide recommendations to establish or strengthen recovery capabilities. This potential impact on an organization can also be measured based on factors from technical, economical, organizational, legal, or regulatory domains.

1.3 Thesis Hypothesis and Contribution

Motivated by these observations above, this thesis makes the following contributions to the field of decision making for adopting a new technology in an organization. The contributions mentioned here are related to cloud-based services, which are chosen as a use case to apply the methodology developed. Also, these contributions have their basis in the following hypothesis (Hx) and research questions (Rx.y) as mentioned below:

H1: A trade-offs-based strategy for a decision regarding the adoption of cloud-based services leads to the selection of a best alternative.

R1.1: What are factors that influence this decision?

R1.2: How can a quantified trade-offs-based strategy be established?

H2: Performing an impact analysis before adopting cloud-based service leads to incorporating appropriate counter-measures against failure.

R2.1: Which factors have to be considered for such an impact analysis?

R2.2: How can impact be predicted in quantified terms?

Based on these hypothesis and research questions, a survey is to be performed as the first contribution, with organizations who either have adopted cloud-based services, or plan to do so in future. The aim of this survey is to identify and evaluate factors that influence the decision of adopting a new technology. Secondly, a quantified methodology, for selecting the best alternative, based on multi-attribute decision algorithms is to be developed and implemented that supports a trade-offs-based decision. This methodology would also encompass the modeling of interrelations amongst the relevant factors along with any contradictory relationships, that might exists. In addition, a predictive and quantified impact analysis method is to be developed to predict the consequences of adopting the best alternative on an organization. All these contributions are made by taking the specific scenario of cloud-based services under consideration. Finally, this thesis also evaluates the generalizability of the trade-offs-based decision methodology developed within the thesis. For this evaluation the scenario of providing Internet connectivity on-board of trains will be studied.

1.4 Thesis Outline

The remaining chapters of this thesis are organized as follows. Chapter 2 discusses related work and concepts that lay the technical foundation upon which this thesis stands; including MCDA and decision analytics of new technology, specifically that of CC. Analysis of related work leads to identification of an existing gap in the current research efforts for decision making of adopting CC, and hence derives contribution opportunities.

Chapter 3 discusses the relevance and complexity of the developed methodology within the context of cloud-based services. Survey results of factors identified and their interrelations are presented, discussed, and analyzed. These factors form the foundation of the framework and algorithms used within TrAdeCIS.

Chapter 4 discusses the design and implementation of the methodology of trade-offs-based decision for the adoption of cloud-based services. The main components of this methodology consist of identification and modeling of relevant factors, relative ranking of alternatives based on its performance for each factor, and a trade-offs establishment for contradictory factors. This chapter also analyzes the relevance of two MCDA algorithms – Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytical Network Process (ANP) – in the decision process of adoption of any technology. Finally, the impact analysis methodology is developed and illustrated to predict the impact an alternative will have on an organization in case of failure.

Chapter 5 evaluates the methodology developed and its implementation in terms of (1) applicability of algorithms, (2) generalization of TrAdeCIS, and (3) results based on the implemented prototype of TrAdeCIS. Performance test results show that the developed methodology is scalable to a high number of factors and alternatives. Also, the applicability of TrADeCIS to other domains than that of cloud-based service proves its extendibility to the decisions pertaining to different technologies.

Chapter 6 finally summarizes and concludes the thesis. It also validates all hypothesis and contributions made in this thesis.

2 Related Work

This thesis addresses a complex and interdisciplinary topic of adopting a new technology in an organization. This chapter, therefore, provides an overview of important thematic areas touched within this thesis. Related work in terms of comparable approaches, efforts, or implementation work is outlined and discussed to allow a better assessment of this work's focus and impact. This chapter addresses four issues: The distinct scope of work shall be defined, key terminology and important notions of decision making from a technical, economical, and organizational point of view shall be discussed, state-of-the-art where available shall be presented, and gaps will be identified and documented.

2.1 Definition of Scope And Terminology

Decision of adopting any technology in an organization touches thematic dimensions of decision analytics, technology, economics, organizational influences, and law. While decision analytics is the tool based on which a decision adoption methodology can be de-

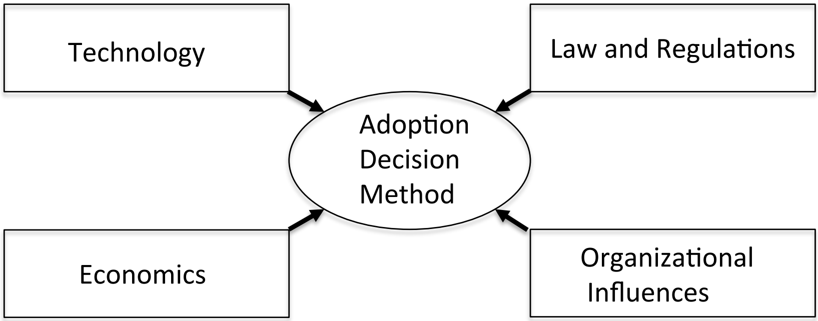


Figure 2.1: Principle Thematic Dimensions Studied

veloped, all other dimensions serve as the factors or criteria that influence this decision process. Figure 2.1 shows and relates these dimensions accordingly. For the dimension of technology this work will primarily focus on Cloud Computing (CC), by means of taking it as a use case on which the developed methodology will be applied and validated. From the economical perspective, this work is motivated by understanding the factors that can evaluate the returns and investment to be made for adopting the technology of CC. For the dimension of organizational influences, this work will identify the changes needed in terms of structure, management, or control, when CC is adopted in an organization. Finally the legal and regulatory perspective studies constraints that any alternative cloud-based service has to abide by in order to be legally compliant. All these domains can be sub-categorized into quantitative and qualitative factors. While quantitative factors consist of factors that can be measured or have numerical statistical data (*e.g.,* cost, availability, throughput), qualitative factors are more subjective in nature (*e.g.,* control over data and applications, legal compliance). These four principle dimensions addressed so far are mutually inter-related. Normally, one also has to trade-off certain criteria or factors for others, specifically when they are contradictory to each other. Hence, each dimension influences directly one of the core results of this thesis, namely the methodology developed to make the decision of adopting a new technology in an organization. Consequently, this methodology has to encompass technological, economic, organizational, and legal and regulatory requirements and limitations. Therefore, to assist a decision maker to focus on relevant factors, their priorities, and performance of available alternatives, methods are needed that help them to model their requirements. A taxonomy can be built for such purposes that models all the factors and their interrelations. A taxonomy is a classification of things or concepts that includes different facets of the data, including relationships and other metadata that provide additional information (*e.g.,* properties) of the data that are being described. Also, this work will perform an impact analysis that will take into account loss associated with adopting cloud-based service if there is any unforeseen technical or business failure. People and organizations face situations where various complex decisions are to be made on a daily-basis. These decisions have been divided in following main types [58]:

Choice Decision: These decisions include selection of the single best option or a set of equivalent or incomparable best options.

Ranking Decision: In these decisions, numerous available alternatives are to be ordered from best to worst. Such ordering uses several techniques such as weights of alternatives across several criteria by making pair-wise comparisons. In pair-wise comparisons two alternatives or criteria are compared in terms of which one is preferred, or has greater amount of some quantitative property or performance.

Sorting Decision: For these decisions the aim is to put the options into ordered and pre-characterized categorizes. This grouping is done based on descriptive and predictive reasoning.

The decision to adopt a new technology can be categorized as a ranking problem as it includes multiple criteria based on which multiple alternatives are to be ranked. Multi-criteria Decision Analysis (MCDA) is such an approach of solving a complex ranking problem by disintegrating it into manageable pieces, so that the several available alternatives can be ranked from the most optimum to the least optimum option [58]. An optimum option is a term for quantifying the desirability or preference of a particular alternative. The desirability or preference of an alternative is measured by its performance for each factor and criteria, and the priorities of these factors. For example, selection of an alternative "A" can be considered to be most optimum, if it performs better than all other available alternatives with respect to factors that have relatively higher priorities. Therefore, there does not exists a unique optimum solution for such decision problems because the selected alternative is based on decision-maker's preferences. MCDA analysis can be performed to rank the alternatives that involves following problems:

Multiple Objective Optimization Problems: Such problems include establishing trade-offs between multiple objectives. Here the number of alternatives or solutions are not known in advance and can only be identified after solving a mathematical model.

Multiple-criteria Evaluation Problems: These problems include a finite set of alternatives, and their performance in multiple criteria are identified in the beginning of the analysis. The methods solving these problems can either be used to rank or sort the available alternatives.

As the decision to adopt any technology involves a finite and pre-known set of alternatives and criteria, it can be specifically categorized as a multiple-criteria evaluation problem. For example, in case of Cloud Computing decision has to be taken with respect to selection of service models such as that of [11]:

Infrastructure-as-a-Service (IaaS) provides computing resources specifically that of virtualized hardware (*e.g.,* virtual machines, servers, storage).

Software-as-a-Service (SaaS) is a software delivery model, which provides software licenses (*e.g.,* virtual desktop, email, games) on a subscription basis.

Platform-as-a-Service (PaaS) provides a platform (*e.g.,* hardware architecture, operating systems, runtime libraries)

Also, clouds can be differentiated based on ownership and access into following deployment models:

Private Cloud is cloud infrastructure operated for single organization use. Deploying private cloud provides high control over the data and application. However, it also requires high degree of engagement by an organization in terms of virtualizing the environment and managing it.

Public Cloud is provided over the Internet. It is hosted, operated, and maintained by external service providers. This restricts the control of an organization on its own data and applications. However, it provides hassle free access to large pool of resources, as per requirements.

Hybrid Cloud is a collaboration between private and public cloud. In such a case, an organization can decide to host sensitive data on the private cloud, but use public cloud for business critical applications.

2.2 Decision Analytics for Cloud Computing

There have been efforts in the past to develop a method for the decision of whether to move the legacy infrastructure into cloud or not. [7] and [123] propose two different approaches. While [7] compares the cost of using a cloud-based service with costs of a datacenter on an hourly basis, [123] presents an approach to compare the costs of leasing and purchasing a CPU (Central Processing Unit) over several years. Both of these approaches only consider cost as a factor, when there are multiple factors from technical, economical, legal and regulatory, and organizational domains that must be considered. However, this approach is not open to an extension to multiple factors (that can have different measurement units) and to factors that are of qualitative nature, which is a characteristic of such a decision [82], [125].

In addition, techniques for brokering Service Level Agreements (SLA) for cloud-based services have also been developed in [3], [5]. This research takes into account different aspects of SLA and apply multiple objective optimization while selecting the best suited cloud-based services as per requirements of the organization. The policy broker sets constrains and objectives on multiple factors of SLA, such as that of best cost per time unit, minimum accepted availability, or highest storage capacity at cheapest price. Different alternatives are then evaluated based on their fulfillment of these different objectives or constraints. However these techniques are restricted to predefined and simplistic interrelations and objectives (without including any priorities to the objective fulfillment), and look into what CSPs promise via SLA rather than the actual performance values of all alternatives.

In the past MCDA also has been performed for the decision of outsourcing [121], [124]. However, this research is restricted to a number of predefined factors or applications for taking a decision. For example [81] looks into the complexity of migrating a web server to Cloud that can be mitigated by a decision support system based on MCDA, which is capable of enhancing the quality of Cloud infrastructure service selections and Cloud Virtual Machine (VM) image selections. Research on a cloud adoption decision process suggests various approaches such as that of Goal-oriented Requirements Engineering (GRE) ([15], [134]), and a quantified method for MCDA [82], [103]. GRE-based approaches are based on a step-by-step process of fulfilling requirements of the cloud user and are qualitative in nature. MCDA based approaches followed in the past were quantitative in nature; however, failed to evaluate impact such an adoption will have on an organization and did not incorporate business-oriented aspects in the decision. Also, these approaches only consider the hierarchical interrelations between factors, which in turn leads to restrictions in modeling of any other interrelations (*e.g.,* all factors connected to every other factor in a mesh network, or all factors connecting to same factor, forming a star network) that might exist. In addition, they do not establish a trade-offs strategy, where conflicting factors are involved. A trade-offs strategy refers to the technique of reducing or forgoing one or more desirable parameter in exchange of increasing or obtaining other desirable outcomes in order to maximize the total return.

Table 2.1: Comparison of Existing Decision Analytics Methodologies

Features	**Cost--driven Approaches**	**SLA--based Brokerage**	**MCDA--based Approaches**	**TrAdeCIS**
Technical Considerations	No	partially	partially	Yes
Economical Considerations	Yes	partially	partially	Yes
Organizational Considerations	No	partially	No	Yes
Legal and Regulative Considerations	No	Yes	No	Yes
Inclusion Of Priorities and Interrelations Of Factors	No	No	partially	Yes
Establishing Trade-offs	No	No	No	Yes

Therefore, all these approaches have a narrow focus while selecting the best alternative as per preferences of factors that influence such an adoption decision. Even though some approaches use algorithms of MCDA that can encompass multiple factors and alternatives, a holistic approach has never been developed before, that explicitly undertakes a combined understanding from the technical, economical, organizational, and legal and regulatory perspective at the same time. As shown in Table 2.1, the comparison of related work to TrAdeCIS developed in this thesis is based on five key features; "Yes" describing the presence and "No" denoting the lack of that feature.

None of the above mentioned related work develops or studies, and quantifies the decision of adopting cloud-based service in an organization. This decision can encompass the selection of (1) CSP and their service offerings, (2) deployment model, or (3) service model. Also, those approaches do not account for on how influencing factors, their priorities, interrelations, and contradictions from multiple domains can be included in such an analysis. Therefore, this thesis fills the gap by developing a trade-offs-based decision methodology to address all the open issues.

2.2.1 Algorithms For Multi-criteria Decision Analysis

The decision of adopting any technology in an organization is categorized as a Multiple-criteria Evaluation Problem. Therefore, a brief discussion and analysis of various algorithms to solve such problems is discussed and analyzed below. These algorithms aim to rank the alternatives based on the relevance of factors, and performance of all available alternatives per factor. Therefore the highest ranked (or most optimum) alternative will be an alternative that matches the requirements more closely than any of the other available alternatives.

2.2.1.1 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

This method was first developed in 1981 [55], and was later presented and modified several times [68], [130] in the community of decision making. The basic principle that the selected alternative should be closest to the best solution (positive-ideal solution) and farthest away from the worst solution (negative-ideal solution), however, remained same in all these modifications. This implies that TOPSIS simultaneously considers the distance of each alternative to the ideal solution and negative ideal solution, and then selects the alternative that is relatively closest to the ideal solution as the best alternative [117]. TOPSIS does pair-wise comparisons of all alternatives across all the criteria and facilitates trading-off a poor performance of an alternative in one factor by a good performance in another factor. Pair-wise comparison is a process of comparing alternatives in pairs to judge which of the two alternatives is preferred, has better performance with respect to a factor, or whether or not the two alternatives are performing at the same level with respect to a factor. Mathematically, TOPSIS follows the following steps:

1. Construct an alternative performance matrix of m alternatives and n criteria, where performance or score of each alternative for every criteria is known. Let X $= (x_{ij})$ be such a matrix where each element of the matrix $((x_{ij}))$ is the performance of alternative i with respect to criteria j. The size of the matrix is $m * n$. Also, let J be the set of benefit attributes (to be maximized) and $J^{'}$ be the set of negative criteria (to be minimized).

2. Normalize the alternative performance matrix. This step is performed to transform the attributes having different dimensions into non-dimensional attributes, hence allowing comparisons across criteria. Normalized weights are obtained as shown by the following equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{\substack{1 \le i \le m \\ 1 \le j \le n}} x_{ij}^2}} \tag{2.1}$$

3. Construct weighted normalize matrix, where each weight or priority is represented by w_j for $1 \leq j \leq n$. This step is performed by multiplying each column of the normalized alternative performance matrix with the priority of respective

criteria or factor. An element of the new weighted alternative performance matrix is:

$$v_{ij} = w_{ij} * r_{ij} \tag{2.2}$$

4. Determine positive ideal solution (A^*) as follows:

$$A^* = [v_1^*, v_n^*] \tag{2.3}$$

where $v_j^* = max(v_{ij})$ if criteria $j \in J$ or $v_j^* = min(v_{ij})$ if $j \in J'$

5. Determine negative ideal solution ($A^{'}$) as follows:

$$A^{'} = [v_1^{'}, v_n^{'}] \tag{2.4}$$

where $v_j^{'} = min(v_{ij})$ if criteria $j \in J'$ or $v_j^{'} = max(v_{ij})$ if $j \in J$

6. Calculate the distance for every alternative j to the positive-ideal solution (A^*) denoted by S_i^* as follows:

$$S_i^* = \sqrt{\sum (vj^* - v_{ij})^2}, for 1 \leq j \leq m \tag{2.5}$$

and to the negative ideal solution ($A^{'}$) denoted by $S_i^{'}$ as follows:

$$S_i^{'} = \sqrt{\sum (v_j^{'} - v_{ij})^2}, for 1 \leq j \leq m \tag{2.6}$$

7. Compute the relative closeness coefficient for each alternative:

$$C_i = \frac{S_i^{'}}{S_i^* + + S_i^{'}} \tag{2.7}$$

where C_i lies between 0 and 1. The closer C_i is to 1, the higher is the priority of the i^{th} alternative.

TOPSIS has been used in the past to make various decisions such as that of selection of financial products [83], energy planning

[63], or vertical handoff decision algorithms for heterogeneous wireless networks [108]. TOPSIS is an appropriate method to also quantifiably rank alternatives for the decision of adopting a new technology due to its simplicity and ability to consider a non-limited number of alternatives and criteria. In addition, it encompasses relative priorities for all the factors along with respective performance of alternatives per factor. Furthermore, as the algorithm normalizes the input values, performance values of alternatives can have different measurement units.

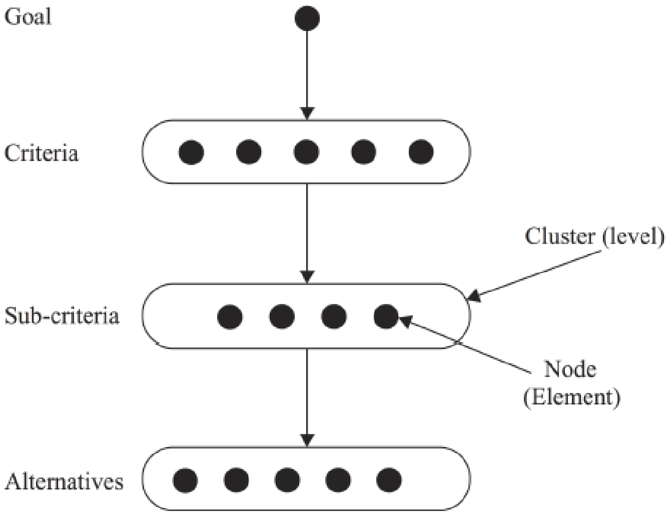


Figure 2.2: Linear Hierarchy of AHP [58]

2.2.1.2 Analytic Hierarchical Process (AHP)

Decision making with AHP involves a hierarchy of criteria and sub-criteria based on which alternatives are ranked [100]. AHP is considered for a decision problem with a goal to be reached (*e.g.,* ranking alternatives), with more than one alternative ways of reaching the goal (*i.e.,* available alternative solutions), and multiple criteria against which the alternatives need to be evaluated. A criterion can be divided into multiple sub-criteria, which will be part of next lower hierarchy to the hierarchy of the criteria. For example, a factor of migration time can be divided into sub-criteria of high, medium, and low migration time. Therefore, the problem to be solved is represented in a hierarchy that descends from the overall objective or goal, down to criteria and its sub criteria, and finally to alternatives from which the choice is to be made. Hierarchy in AHP indicates a relationship between elements or nodes of one level (cluster) with those of the level (cluster) immediately below (cf. Figure 2.2). Once the hierarchy has been constructed, the decision maker analyze it through a series of pair-wise comparisons that derive priorities of the criteria and alternatives [100]. The latter of the two is based on the performance of each alternative per criteria. The steps of AHP to rank the alternatives can be summarized as follows:

1. Model the decision to be taken as a hierarchy that contains the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives.

2. Establish local priorities among the elements of criteria cluster by making pair-wise comparisons of all the elements in the hierarchy of criteria. In making these comparisons, decision makers use elements' relative importance with respect to their impact on the decision of selecting an alternative. Arrange the priorities in a matrix and calculate normalized principle Eigen vector of the matrix. The same process is repeated for all the sub-criteria.

3. In case of hierarchy that has more than one level of criteria calculate global priorities of sub-criteria. Global priorities are obtained by multiplying local priorities of the level N+1 to the priority of level N.

4. Final decision is obtained based on the performance of each available alternative with respect to different criteria (which also have different priorities).

It has found its applicability in various fields of multiple criteria decision making such as that of operation research, strategy planning, and resource allocation [29]. However, there have been criticisms such as a very complex decision results in a very complex hierarchy, and high number of pair-wise comparisons is not feasible within acceptable time limits. Also the question, for example, if the structure of a hierarchy needs to be flat (with few levels and many elements on the levels) or tapered (with many levels and few elements on one level) can lead to contrasting ranking of alternatives [51]. Therefore, a method is needed that can support interrelations between any desired elements of the decision that are not necessarily to be structured as a hierarchy.

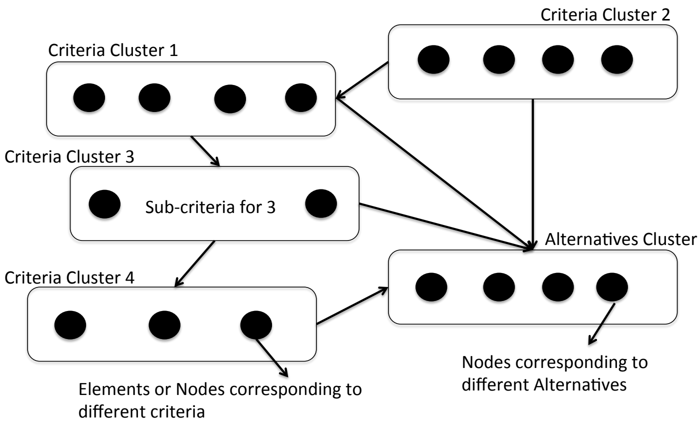


Figure 2.3: ANP Network

2.2.1.3 Analytic Network Process (ANP)

ANP, as opposed to AHP, models the decision as a network of clusters, wherein clusters are no longer necessarily connected in a hierarchy as shown in Figure 2.3. In ANP, all criteria are represented as a cluster, and their sub-criteria (if any) are modeled as elements or nodes within that cluster. Also, all available alternatives constitute an additional cluster. ANP is the only method where a possibility to model dependencies or interrelations between any set of elements exists [58]. Interrelations between criteria and alternatives are modeled as inner or outer dependencies or connections of clusters. While an interrelation between a node or an element within a cluster is termed as inner dependency, interrelations between two different clusters is called outer dependency. The steps of ANP can be summarized as follows:

1. The first step is to model the decision to be taken. In ANP criteria and alternatives are represented as clusters (comprising of nodes) of a network. The clusters are connected based on the interrelations that exist between factors. Also, all the clusters of criteria are connected to the cluster of alternatives, as based on these factors all alternatives are to be evaluated.

2. For all the nodes that are inter-connected comparison matrices are generated by performing pair-wise comparisons of interrelated nodes.

3. Principle Eigen vector is computed for all the comparison matrices. The values of the Eigen vectors are called local priorities corresponding to all connections between the nodes in the network.

4. All the obtained Wigen vectors are represented as column vectors in the matrix, hence forming an unweighted super matrix.

5. In the next step the unweighted super matrix is normalized to calculate the weighted super matrix.

6. The limit matrix is now calculated, which is the weighted super matrix raise to the power of k+1, where k is an arbitrary positive integer. The values in the limit matrix specify the ranking for alternative solutions.

[82] suggests ANP as the favorable evaluation method for evaluating cloud-based services due to its ability to incorporate com-

plex criteria networks during the evaluation. More complex criteria networks enable a more realistic modeling of criteria dependencies. Also, [126] presents an ANP method to evaluate the QoS of cloud service architecture. This method selects the most optimum architecture. In other words, the ranking of the architecture obtained by ANP is equivalent to utilizing a model that will filter the architectures that does not provide the desired quality level. In addition [126] mentions that as ANP allows for multiple interrelations between any two factors and alternatives, it can also be used to analyze trade-offs based decisions.

2.3 Transition to Cloud-based Services

Cloud-based services have the ability to pay for use of computing resources on a short-term basis as needed and then release them as per the need [7]. Also, CC includes lower implementation and maintenance cost [71]. This in turn leads to a major transition in terms of Capital Expenditure (CAPEX) model to Operating Expenditure (OPEX) model. In addition, this reduces the barriers in adoption of cloud-based services as infrastructure is owned by the CSP, it does not need to be purchased at one-time, and is scalable that facilitates growth of an organization. IT departments save time, cost, and effort in terms of developing, deploying, securing, and maintaining applications and infrastructure [7]. In terms of organizational benefits CC improves the agility and flexibility of organizations, owing to scalability and availability of high-performance resources [75]. Even though there are numerous advantages of CC, there are several risks associated with security and privacy of data and applications [104]. Following section discusses the models developed with respect to transition of legacy infrastructure and applications to CC to improve its performance, understand economical returns, and consequent organizational impact. Also, several attempts made in the research community to identify the factors that influence such a transition or adoption of cloud-based service, are discussed below.

2.3.1 Requirement Elicitation Methods

Developing a decision support system is complex specifically when the user preferences are unknown or not modeled with accuracy. Requirement or preference elicitation refers to elicitation of user preferences by capturing or collecting them, which in turn assists in decision making. It is crucial for such a problem to model user's preference accurately (including hidden preferences) and avoid redundancy [134]. However, [134] claims that for making the decision of adopting cloud-based services only initial set of requirements should be identified before searching for a CSP, so that later negotiations as per requirements can be made. But, this can lead to biased and inaccurate decision, as complete user preferences are not known. Traditional exploratory methods of eliciting such as that of interviews, questionnaires, surveys, or analysis of existing documentations have been applied by CSPs and researchers in the past to understand the requirements of the users and thereby improve the offered services or adoption of cloud-based services [47], [49], [66], [72], [74], and [87]. However, these efforts are narrow in its focus of identifying the relevant factors and their interrelations. Therefore, there is an existing gap of developing a taxonomy of factors that consists of all relevant factors and their interrelations that are influence the decision making of adopting CC.

2.3.2 Technical Models

As the resources of CC are shared across different users, it is important to logically and physically separate the data and applications (belonging to different users) that are stored on the cloud [137]. [70], [137] explore the methods to segregate and encrypt the data to ensure security and privacy of data on the cloud. Currently, CSPs isolate data within single tenant boundary. However, with changing times there is a need of systems like Muti-tenancy Authorization Systems [112] that support cross-tenant collaboration using authorization as a service. In CC as various multiple instances of resources are available, scheduling algorithms are needed in order to efficiently allocate computing resources. [29] develops a task-oriented resource allocation algorithm by pair-wise comparing the tasks and user preferences, and then finding the best alternative resource by using AHP. [128] developed a dynamic resource allocation algorithm that avoids overloading of the physical machines by measuring the uneven utilization of the servers. They also predict the future load of applications by observing usage patterns. However, allocation of resources is dependent on many other factors, such as network bandwidth, response time, reliability, and cost, that are not included in any of these models.

Research and development in the field of federated cloud is still in nascent era [7]. There are only few efforts in the field of energy-efficient strategies for provisioning resources [93], [13], and negotiating them in inter-cloud and federated cloud. Simulation tools such as CloudSim [18], and testbed such as Open Cirrus [8] have been developed to model and simulate the CC systems and applications, both is single and federated cloud environments. Such tools enable simulation of data centers, Virtual Machines (VM) and resource provisioning policies. However, lack of common accepted standards lead to delivering of technology by the CSPs that is based on different proprietary Application Program Interfaces (API). There is only a single cloud standard available – the Open Virtualization Format (OVF) – for facilitating the mobility of virtual machine [28]. However, this alone does not make cloud solutions interoperable. In other words, the customer is not able to use service across multiple clouds using a common management API [110]. There have been, therefore, efforts to develop a vocabulary for describing services [76], discovery of services using OWL ontology [94], and management API for interacting between different clouds [24]. The description of services included in vocabulary give organizations support for information integration, extensibility, and resilience to change [24]. However, this technical description only focusses on interoperability of an application, thereby excluding other relevant aspects of cloud-based services. Even though these models improve the performance of cloud-based services, they do not simultaneously consider different technical factors and their interrelations to improve various aspects of cloud-based services. Also, these models do not enable an organization to differentiate between different available alternatives, and identify appropriate deployment or service model as per the requirements. Therefore, a methodology is needed that considers multiple relevant factors and is able to make a decision for an organization to select the most suited alternative to requirements.

2.3.3 Economical Models

Cloud-based services manage under- or over- provisioning of resources with the possibility of dynamic resource allocation, which benefits from economies of scale leading to high cost savings [19]. An optimal cloud resource provisioning algorithm by formulating a stochastic programming model was developed in [19]. This algorithm allows for minimizing total cost of resource provisioning even with reserving the resources in advance, when the price and demand are uncertain. [71] developed a tool for cost analysis of cloud by Total Cost of Ownership (TCO) and Utilization Cost (UC) of cloud-based services. Cost calculation in cloud-based services is the total sum of cost of server, software, support, network, power, cooling, facility, and real-estate. TCO not only includes the capital cost, but also the cost of operating the IT infrastructure. UC is dependent on the actual utilization of the resources (*e.g.,* servers, VMs) at the instant of calculation. There have been efforts in the past to make a decision whether to move the legacy infrastructure into cloud or not. [38] and [123] propose two different approaches. While [38] compares the cost of using a cloud-based service with the costs of a datacenter on an hourly basis, [123] presents an approach to compare the costs of leasing and purchasing a CPU (Central Processing Unit) over several years. Both of these approaches only consider cost as a factor, when there are multiple conflicting factors that must be considered. [91] introduces a transaction cost-based decision regarding outsourcing. This is based on the minimum cost and maximum possible profit for each alternative. There also has been an attempt to use utility-based mechanism to support SLAs in order to balance the performance of applications and the cost associated with them [21], and allocation of bandwidth and its associated pricing [92]. Both of these efforts particularly investigate the service profit and customer satisfaction.

However, all these economical approaches are not open to an extension to multiple factors (that can have different measurement units) and to factors that are of qualitative nature, which is a characteristic of such a decision of moving to cloud-based services [82].

2.3.4 Organizational Models

CC has been developed as a new technology with several technical and economical advantages. The success of cloud adoption is also dependent on understanding its influence or impact on organization. However, the related work in the domain of understanding organizational impact is very limited. The influence of CC can be in terms of transformation of existing business process, applications, and data to fit into CC, size of organization, knowledge, and expertise of human resources [47], [74], [99]. In addition, [129] discusses how cloud-based services will affect the authority and role of IT department in an organization. Therefore, an impact analysis methodology is needed that can measure in full the impact of adopting cloud-based services on an organization.

2.3.5 Inclusion of Legal and Regulative Considerations in Cloud Adoption Decision

Organizations have many expectations from cloud-based services associated with access, reliability, security, confidentiality and privacy, liability, or ownership of data [109]. Failure to address these issues by CSPs and their compliance to any applicable laws and regulations can be unacceptable to an organization. Related work focuses on some of these specific facets of legal and regulative compliance of CC. [4], [20], and [64] focus on data protection issues in CC. [65] concentrates on issues regarding applicable laws and regulations in CC federation scenarios. Other efforts include cross boarder data flow issues [107], anti-trust [127], and security [62] considerations. While this related research discusses the legal and regulative in depth their consequences on other technical, economical, and organizational factors effecting cloud adoption decision CC are not evaluated.

Table 2.2: Comparison of Models Assisting in the Transition to Cloud-based Services

Features	Preference Ellicitation Methods	Technical Models	Economical Models	Organizational Models
Inclusion Of Priorities and Interrelations Of Factors	partially	No	No	Yes
Legal and Regulative Considerations	No	No	partially	Yes
Trade-offs Based Quantified Decision	No	No	No	Yes
Impact Analysis	No	No	No	Yes

As shown in Table 2.2, the comparison of related work of transition to cloud-based services to TrAdeCIS developed in this thesis is based on five key features; “Yes” describing the presence and “No” denoting the lack of that feature. This, therefore, marks the gaps existing in the current research and helps in identifying available contribution opportunities.

2.4 Contribution Opportunities

As shown in this chapter there is an extensive research dedicated to achieve high flexibility, performance, scalability, and availability of cloud-based services in a cost effective manner. However, success of CC is dependent of efficient and optimal decision-making while adopting cloud in an organization. Such a decision process involves predicting best alternative and most optimal path, even in the scenarios of uncertainty and incomplete information. Thus, the related work research present in this chapter has revealed the following:

1. Current approaches assisting in the decision of adopting cloud-based services are very narrow in their inclusion of relevant factors and their interrelations, *i.e.,* all technical, economical, and organizational factors and their interrelations are not included.

2. Current methodologies do not identify that many of the relevant factors can be contradicting. Hence, these approaches lack the possibility of making a quantified trade-offs-based decision for conflicting factors.

3. Also an impact analysis methodology for predicting the impact an alternative will have on an organization is missing from the current research literature.

Having identified these above shortcomings and in direct relationships with the observations made in Section 1.3, the following opportunities for scientific contributions in the area of decision making of adopting cloud-based services in an organization have been revealed:

1. Identifying relevant factors that influence the decision of adopting CC, and building taxonomy of these factors and their interrelations. In addition a method is to be developed to rank and prioritize these factors.
2. Development of a quantified trade-offs-based methodology for the decision of adopting CC so that trading off in case of conflicting factors is possible. This will be based on MCDA algorithms as they give a possibility of ranking all available alternatives based on multiple factors, and thereby identify the most optimum alternatives as per the requirements.
3. Implementation of a web-based system that allows for use case based evaluation and extensibility testing of the methodology developed – TrADeCIS – within this thesis.
4. Development of a predictive impact analysis methodology that allows to predict the impact the top ranked alternative (as per the trade-offs-based decision methodology) will have on an organizations after its adoption. This makes organizations aware of possible losses, risks and the need of any preventive countermeasure in advance.

Hence Chapters 3 to 6 present a detailed design, analysis, and evaluation of the methodology developed within this thesis to make trade-offs-based decision for adopting a new technology in an organization.

3

Adoption of Cloud-based Services

Adoption of cloud-based services is a critical decision, not only because of the impact it has on an organization, but also due to the availability of diverse offerings by various Cloud Service Providers (CSP). Also, there exists a wide array of deployment models and service models, which an organization can select from based on its requirements. Due to a plethora of options and varied requirements, the relevance and complexity of making an optimal decision increases. This chapter identifies and analyzes factors and models their interrelations, which influence the decision of adopting cloud-based services in an organization.

3.1 Relevance and Complexity

Growth in the number of service providers and their offerings of any technology raises the need of evaluating the most optimal alternative. This decision is based on the expectations or factors that are used to measure the impact of incorporating any new technology into business for fulfilling IT (Information Technology) needs. In addition, these influencing factors can be from multiple domains, and can be highly interrelated. This can be seen in various technologies as analyzed below.

Deployment of Internet on Train can involve a multi-criteria comparison in the decision of selecting and deploying different on-board signal repeaters such as IP-based data access points, wide-band repeaters, or small cells [89], [78]. These criteria can be interrelated factors from technical (*e.g.,* availability, latency), economical (*e.g.,* cost, revenue), and organizational (*e.g.,* licenses) domains.

Network Function Virtualization (NFV) increases the flexibility to share resources and decrease setup and management cost for Telecommunication Service Providers (TSP) [50]. The possibility of moving network functions to cloud raises questions for TSPs such as that of selection of deployment models [85]. The network function can be moved to a public cloud, or to private ones that are distributed across TSPs infrastructure. Either way, decision will have to be made to select an appropriate cloud-based service that will be based on interrelated factors such as that of performance, reliability, security, or communication between functions.

Cloud-based Services are being offered by numerous service providers such as that of Amazon, Google, or Microsoft. Each of these CSPs offers similar services at different prices and performance levels [18]. While one provider might be cheap for computation, they may be expensive for storage. Also, factors that influence the impact can be interrelated. For example, consolidation of resources and improper logical separation of data by CSPs, can lead to illegal and unethical disclosure of information to unauthorized people [106]. This can lead to monetary losses for the organization

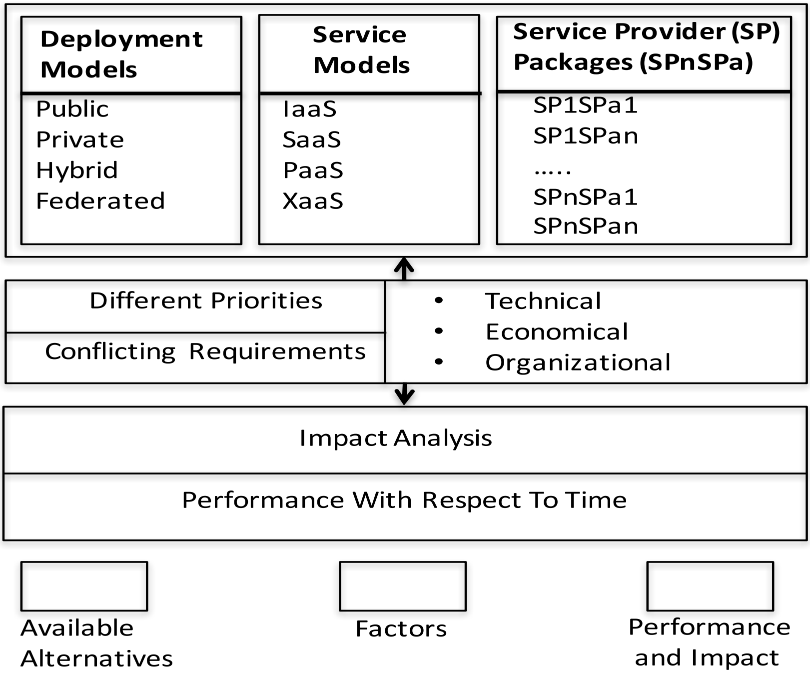


Figure 3.1: Reasons for Complexity of Decision Making in Cloud Computing

that stored data on the cloud. Therefore, cloud-based service must be evaluated from interrelated factors from (1) technical, (2) economical, and (3) organizational perspective. In addition, these factors can vary based on type of the service model and the deployment model under consideration. Furthermore, these factors can be mutually interdependent and conflicting [43], [45]. For example, the costs of cloud-based services are lower, mainly due to the possibility of sharing of resources. This, however, can lead to degradation in performance level, which in-turn may prove costlier to a customer. In addition, these factors can have different priorities or relevance for different organizations based on their expectations from cloud-based services.

Therefore, as shown in Figure 3.1 the decision to adopt any technology (instantiated in detail for cloud-based service) is complex because of following reasons:

1. **Factors** that influence the decision are very complex in itself. They are from various domains (technical, economical, and organizational), and can not be generalized. They vary on a use case basis. In addition, they can be interdependent and conflicting with each other.

2. Cloud-based services are offered in various **deployment models** that are differentiated based on their size, ownership, control, and access of data. Also, services are offered according to different **service models** serving different requirements of infrastructure, platform, and software. In addition, there exist **multiple offerings** per CSP that vary in pricing and functionality.

3. Lastly, the selection of an optimal alternative is based on the **analysis of the impact** it will have on organization. As the performance of an alternative with respect to each factor can not be guaranteed (but can only be of predicted), it is a predictive analysis.

3.2 Influencing Factors and their Interrelations

As identified in Chapter 2 their is a lack of empirical data for the factors that should be considered while evaluating the impact of cloud-based services or decision to adopt cloud-based services in any organization [47], [49], [72], [74], and [87]. Without a common taxonomy and a standardized frame of reference for the factors to be considered, it is difficult for organizations to have a conclusive decision regarding adoption of cloud computing – externally with CSPs or within the organization. Therefore, this thesis follows an exploratory method to collect the relevant factors. This is a qualitative approach, to understand information in depth and analyze diverse and complex data. In order to identify relevant factors, two qualitative methods were used. First is that of a case study, wherein semi-structured interviews were conducted with organizations. Semi-structured interviews were selected because the author was able to narrow down areas or topics that were to be asked. However, author was still interested to hear the experiences of the interviewees. Completely un-structured interview has the risk of not eliciting the topics from the interviewees that are closely related to the research questions under considerations. Second is that of analyzing available literature, both from industrial and academic surveys. Case studies are used for collecting data, where little or no information exists. It helps to understand a case from holistic and real-world perspective [132].

The following sections list and analyze the data collected from case studies conducted with 17 organizations, who have adopted or plan to adopt cloud-based services for fulfilling their IT requirements. These interviews were conducted between June 2013 and October 2014, and their duration varied between 45 and 60 minutes. These interviews were either conducted by the author on landline phone or as face-to-face meetings. Literature review covered reviewing various technical and economic papers, white papers, and surveys provided by industry and academic research.

3.2.1 Details of Organizations Surveyed

The selection of organizations interviewed was based on random and convenience sampling. Random sampling is considered as a fair way of selecting a sample from a given population since every member has same probability of being selected [48]. This was combined with convenience sampling, due to the availability and proximity of participants. Convenience sampling helps to collect information in more depth as participants are in proximity [48]. Bias, which can often result from convenience sampling, was avoided with two countermeasures: (a) Participants were selected with varied geographical scope and domain of expertise. This helped in collecting data that can considered as representative of the complete population. (b) Questions were based on interviewees' experience of adoption of cloud-based services (varied as per their domain of expertise) and with general benefits or challenges associated with the adoption of cloud-based services, therefore, making generalizations possible.

As identified during the survey all organizations use ad-hoc preference elicitation methods ranging from guessing and inventing preferences to imitate past decisions made by competitors. This leads to selection of an alternative that is not optimal, and is based on incomplete preferences. The sample of organizations surveyed consisted of only 17 organizations because during the survey a saturation was reached in terms of factors that were being mentioned by the decision makers of any additional organization. Each of the questions posed to the interviewees were related to at least one of two topics (as shown below) that were identified for these interviews. The author used the topics as opening statement for starting the conversation, and the questions were designed to probe for information that does not come up during the interview.

- **Topic 1:** The factors (technical, economical, and organizational) that should be considered while making a decision to adopt cloud-based services for fulfilling IT requirements.
  - What are the key reasons for adopting a cloud-based solution?
  - What are the limiting factors and risks for selecting a cloud-based service?
  - What are the factors that decide the eligibility of candidate to be migrated to cloud-based solution?

  - What are the factors that decide which deployment model will be selected?

- **Topic 2:** Interdependencies between these factors.

  - Are any of the factors interdependent and/or mutually conflicting? If yes, then how?
  - What is the impact of migration to cloud-based service on an organization.
  - What is the process of evaluating success or failure of adoption of cloud-based services?

These topics aimed to identify requirements or factors that influence the decision of adopting cloud-based services in an organization. These factors can be measurable or qualitative in nature and they effect the evaluation of several available alternatives of cloud-based services. Identification of these factors is relevant for this thesis, as the decision making of adopting cloud based services requires modeling of these factors in the decision model and ranking all available alternatives per relevant factor.

Table 3.1: Details of Organizations Involved in Case Studies

Organi--zation	Domain of Expertise	Organization's Size	Geographic Regions Served
O1	ICT Provider	60000	Europe, USA, Singapore
O2	Health Insurance	450	Switzerland
O3	Communications	20000	Switzerland
O4	IT Infrastructure Provider	5000	Europe, USA, Australia, China
O5	Financial Services	2600	Worldwide
O6	Property and Life Insurance	4000	Switzerland
O7	Professional Services	180000	Worldwide
O8	Networking Solutions	67000	Worldwide
O9	ICT Association	-	Switzerland
O10	Financial Services	140000	Worldwide
O11	Banking Services	255000	Worldwide
O12	Technology and Consulting	431000	Worldwide
O13	Technology and Consulting	305000	Worldwide
O14	IT Services	318000	Worldwide
O15	IT Infrastructure Provider	107000	Worldwide
O16	Life Insurance	3000	Switzerland
O17	Digital Media Solutions	12000	Worldwide

Details of organizations who participated in case studies are listed in Table 3.1. Interviewees from these organizations were senior decision-makers with experience of assessing various cloud alternatives. Participation was voluntary, and their identity is kept anonymous, while reporting the collected data and its analysis. This was mainly due to the confidentiality and sensitivity of data and opinions that were shared by the decision makers of various organizations. These case studies and its results are suitable and complete for the purpose of the thesis because it establishes the need of a decision methodology that accommodates both qualitative and quantitative factors and their interrelations (including contradictory influences). Also, it leads to an analysis and modeling of qualitative factors such as that of legal and regulative requirements with the inclusion of all relevant interrelated factors.

3.2.2 Factors Identified

Based on the semi-structured interviews and the literature review it was identified that adoption of Cloud Computing comes with prominent and definite changes in an organization, which can be broadly categorized into following categories.

- **Technical:** The possibility of high performing infinite computing and storage resources available on demand is the most discussed and quoted benefit of CC, which comes with inherent challenges of security and privacy.
- **Economical:** Elimination of up-front costs leads to a change in traditional economical models in place for calculating the associated cost and the return on investment.
- **Organizational:** On one hand CC transfers the risk of operating the infrastructure to CSP. On the other hand it brings challenges in terms of loss in control over the data, and unknown location of data storage (risks in legal and regulative

compliance). Also, the organization has to change its structure, management, and business models so as to accommodate the technical changes that CC brings with it.

Therefore, the qualitative data of identified factors from exploratory research was categorized in three categories of technical, economical, and organizational factors. The data (both of case studies and literature review) was aggregated, converged, and aligned in an XML taxonomy, thereby helping in identifying multiple occurrences of factors and cross case-study synthesis. Web Ontology Language (OWL) is another a language that allows the expression of semantic constructs using classification. However, XML is used in this thesis instead of OWL for building taxonomy because XML Schema is much richer in defining structures for information elements and larger set of data types [67]. OWL has more inference capability but that is out of scope for the modeling of factors within this thesis. Following means ensured the completeness of the identified factors:

- **Selection of representative population of decision makers:** As shown in Table 3.1 the decision makers who participated in the survey had gained experience from small, medium, or large scale organizations who served different countries across the globe. Also, the domain of expertise of these organizations was a array of different fields. This ensured identifications and analysis of different domain specific requirements based on which cloud-based services have to be evaluated.

- **Extensive literature review corresponding to all relevant facets:** In addition to surveys, extensive literature review of current research on technical, economical, organizational, legal and regulative aspects of CC ensured in-depth analysis of all the factors that also included study of their implications.

Listing 3.1: XML Schema

```
<?xml version=”1.0” encoding=”UTF8”?>
<!DOCTYPE TAXONOMY [
<!ELEMENT TAXONOMY (FACTORS+,RELATIONS?)>
<!ELEMENT FACTORS (FACTOR+)>
<!ELEMENT FACTOR (NAME, DEFINITION, VALUETYPE, TENDENCY, SUBFACTORS?)>
<!ELEMENT NAME (#PCDATA)>
<!ELEMENT DEFINITION (#PCDATA)>
<!ELEMENT SUBFACTORS (FACTOR+)>
<!ELEMENT VALUETYPE (#PCDATA) >
<!ELEMENT TENDENCY (#PCDATA)>

<!ELEMENT RELATIONS (RELATION+)>
<!ELEMENT RELATION EMPTY>


<!ATTLIST FACTORS CATEGORY (Economical|Organizational|Technical) #REQUIRED>
<!ATTLIST FACTOR FACTORID ID #REQUIRED>
<!ATTLIST RELATION RELATIONID ID #REQUIRED>
<!ATTLIST RELATION FACTOR1 IDREF #REQUIRED>
<!ATTLIST RELATION FACTOR2 IDREF #REQUIRED>
]>
```

The XML taxonomy, as defined and developed within this thesis, structures these factors and models all interrelations. As shown in the XML schema in the Listing 3.1 factors can be identified based on their *category* and *factorid*. Also, all these factors have multiple attributes - The attribute of *tendency* specifies if the expected value of the factor from the organizations' perspective should be as high as possible or as low as possible. For example, some factors like price or response time have expectations of lower values (negative tendency) whilst higher values (positive tendency) are desired for throughput or availability. The next attribute is that of *value type* that specifies if the value of a factor can be specified as, string, enumeration, numeric, boolean, list, set, or range. Furthermore, this taxonomy also models all interrelations between the factors that are derived from the analysis of data collected. These interrelations are modeled as (1) hierarchical interrelations, in terms of factors and its sub-factors, and (2) influential interrelations, where a factor and/or its sub-factor(s) influence other factors and/or its sub-factor(s). The granularity of both hierarchical and influential interrelations of factors can vary based on specific scenario under consideration. For example, the factor of data loss can be further sub-factorized into types of counter measures taken by CSP against data loss or leakage, or specific encryption techniques that are desired by an organization. This implies that identifying a complete list of all these granularities is not possible, as this would always be scenario specific. Therefore, these factors that are identified and analyzed below act a guideline in terms of relevant factors that are to be considered while evaluating different cloud-based services.

3.2.2.1 **Technical Factors**

The complete list of these factors from technical perspective, as obtained from interviews with the organizations and literature review, is listed in Table 3.2, and corresponding XML structuring is presented in Appendix A. Their relevance on the decision of adopting cloud-based services are discussed below on a per factor basis:

- **Accessibility:** Effectiveness and accessibility of cloud-based services is dependent on broadband speed. If broadband is unavailable or speed is slow the effectiveness, reliability, and real-time services of the cloud do not get delivered as they are meant to be. Accessibility also includes independence in terms of device through which cloud-based service can be accessed. This is dependent on the usage of standards for implementing the entire technology stack of cloud-based services [115].

- **Application Lifecycle Management:** Application Lifecycle Management (ALM) generally refers to the different phases of software development, from initial planning to retirement. For example, for SaaS CSP is responsible for each phase of the ALM. From an organizations' perspective important phase of ALM with respect to cloud-based services is that of patching and upgrading [135]. CSPs must provide centralized patching and upgrades for applications so that users work with same and latest version of the application.

- **Availability:** Availability of cloud-based services is a crucial factor of defining and identifying appropriate price-performance ratio. Failure of any component within a cloud-based service, must be handled in advance by redundancy. Every physical component, on which service delivery depends, needs to be redundant, since failure of even one component comprises the availability of the entire service. Service Level Agreements (SLA) must define the guaranteed availability, and liabilities and counter measures in case of any failures. One way of classifying the availability of services depending on the behavior of the system during system interruptions, maintenance, and fault or disaster tolerance can be based on if the data integrity is maintained and/or the functionality of the service is interrupted or not [136].

- **Backup:** In order to ensure that the information is not lost organizations often demand data and application backup from CSP. This assures business continuity and chances of data getting lost are reduced. However, CSPs offer this as a premium service, and not every organization might be able to bear the expense. Also backing up data on Cloud is best when the rate of change is less than 10% of the total data per month [114]. Furthermore, the migration of data from one Cloud to other Cloud is not simplistic, owing to the problem of portability. It needs efforts, time and leads to additional expense. This in turn, makes backup an important factor for evaluating cloud-based services. Therefore, SLAs need to specify all parameters such as where and how images of data and applications are stored [1] so that liability and consequences in case of any failure are known in advance.

- **Complexity:** Complexity refers to the difficulty to understand a new technology and how easy it is to use. It can be measured by quantitative and qualitative feedback from users. It is further divided into following sub-factors by [109].
  - **Frustration:** Measures the complexity in terms of perceived difficulty of using and understanding the system.
  - **Flexibility:** Denotes the rigidness of the provided interaction from the service.
  - **Task Adequacy:** Signifies how easy it is to get the system to fulfill important tasks.
  - **Expectation Conformity:** Unexpected behavior leads to increased complexity of the system. Therefore, the service must adhere to expectations of the user.
- **Customization:** Customization refers to the degree a service can be adjusted to ones needs or different type of users [1]. For example, organizations operating in different countries often need to customize the security and access settings based on each region or country s regulations. Highly customizable solutions can be more attractive for such cases. Therefore, it is in the interest of CSPs to offer solutions that have high customizability. The consequences for organization, when choosing a solution that is not highly customizable, depend on the service models. The existing business processes need to be redesigned, if the solution does not allow any customization
- **Data Access:** With moving of the data to cloud-based services, security and privacy concerns rise. There are multiple reasons for this such as that of a CSP - (1) not defining clearly the control and access of data at logical and hardware level, (2) not assuring deletion of all data copies when an owner decides to move or remove the data from cloud, and (3) not implementing right level of encryption. Data access and its associated security challenges are specifically crucial to cloud-based services

when organization outsource their sensitive data to CSPs. In some practical cloud systems, data confidentiality and access control is not only a security/privacy issue, but also of juristic concerns [133]. Data access by developers who are writing new applications for execution will often use a cloud-based object storage service, such as Amazon S3 or OpenStack's storage cloud. To access the data in S3 developers use a Web-services API based on REST principles [114]. These principles are supported majorly by every cloud storage provider. However, the more complicated issue is that of allowing only legitimate users to access the data. This requires implementation of appropriate security and authentication techniques, and strict access control policies from the side of the CSPs.

- **Data Loss:** Basic types of data loss include data destruction, data corruption, and unauthorized data access. This can happen due to failure of any component of cloud-based service, power outages, or security breaches [7]. Data loss can have huge impact on the organization. Beyond the damage to reputation, loss of customers and partners, and loss of intellectual property it could have financial and legal implications too. Therefore, it is important for an organization to evaluate the data in terms of its criticality so that its associated access control [133], encryption, and key management techniques for data backup and data retention strategies can be decided and implemented.

- **Elastic Resourcing:** Elasticity can be measured in terms of bandwidth elasticity, number of VMs, memory and CPU processing power elasticity, or storage elasticity. All the interviewees mentioned public cloud cloud tends to get significant advantage over private cloud because of its capability to handle unexpected hikes in workloads. Therefore, a flexible infrastructure capacity and a lower provisioning time become a critical factor for the adoption of cloud-based services.

- **Fault Tolerance:** Cloud-based services are dynamic in nature, which leads to unexpected system behavior resulting in faults and failures. Fault tolerance is the ability of cloud-based services to serve its purpose even in the presence of failures. Fault tolerance techniques can be categorized either as (1) reactive and proactive, or (2) collaborative and exclusive [113]. However, a cloud-based service consists of multiple components that can belong to one of the stack of infrastructure, platform, or software. Therefore, it is important to identify the faulty component and take appropriate measures accordingly. Also a failure in any given layer usually has an impact on the services offered by the layers above it. For example, failure in middleware (PaaS) can cause errors in the software services built on top of it (SaaS). Similarly, failures in the IaaS layer will have an impact on most of the PaaS and SaaS services. Furthermore, depending on the deployment model an instance of a server in a multiple cloud scenario might run on multiple virtual machines on the hardware of different CSPs. If there is a fault caused at one CSP, it should not effect the others.

- **Functionality and Usability:** As mentioned by interviewed organizations, besides the technological know-how the ease-of use is also crucial for a successful adoption of cloud based services in an organization.

- **Initial Migration and Data Transfer:** Moving or migrating the applications or data to cloud involve high efforts and time from the side of organization. [7] states that migrating data to external locations via network connections can take a long time (over 45 days for 10TB at 20Mbits/sec) and relatively shipping data via hard disks is often proves to be faster. Higher the time and the resources that have to be spent on migration, higher is the cost associated with it. Also, within this time frame their might be some updates in the data itself. Therefore, it is important that data is migrated as fast as possible and is synchronized.

- **Integration:** Cloud integration has very context specific meaning. It can signify (1) integration of application and storage with legacy infrastructure, (2) integration of applications on cloud so that multiple users can access it from multiple devices, or (3) process of configuring multiple applications to share data in the cloud [27]. Interviewed organizations mentioned that integration between SaaS and on-premises legacy applications is one of the top challenges for adopting SaaS.

- **Interoperability:** It means applications running in a cloud is being able to share data and to work exactly in the same manner in any other cloud instance. Interoperability is required not just between different components of cloud service but also between identical components running in different cloud instances. Full interoperability includes dynamic discovery and composition: the ability to discover instances of application components, and combine them with other application component instances, at run time [116]. To achieve interoperability standards are required at all level *i.e.,* at infrastructure, platform, applications, data, and management. Interoperability facilitates accessing stored data in another cloud or communicating with applications in heterogeneous cloud platforms. Therefore, it is important to evaluate APIs provided by CSPs while adopting cloud-based services, so that the solution provided by CSP is flexible and compatible in true sense.

- **Management and Maintenance of Identity Platform:** The identity platform is specifically important in public, multiple cloud, and community cloud-based services [31]. In these deployment models, often many people have access rights to the same and applications. The organizations want to control who has access to resources in the cloud. Without a good identity platform, organizations risk that sensitive and confidential data is accessible by unauthorized entities.

- **Network Quality:** Small and Medium Enterprises (SME) interviewed specially mentioned the importance of taking measures to increase the network quality in terms of bandwidth and connectivity. Network quality is important, because in many cloud architectures (*e.g.,* Amazon Elastic Block Store (EBS) architecture) the data storage layer is abstracted in the compute layer of the application. These compute and data storage nodes are connected via a network [131]. If the network is not of good quality, the application can fail to respond and the performance can reduce considerably.

- **Portability:** Portability is the ability to move a component from one system to another so that it is still usable on the target system [96]. Portability can be broadly divided into data and application portability. The first aspect of data portability is that a organization should be able to retrieve the data from the original service and import it into the target service.The second aspect is that the syntax and semantics of the transferred data should be same or mappable from the source service to the target service [23]. For example, In IaaS, portability refers to the possibility to move VMs between different CSPs (or from a traditional architecture to the cloud). Therefore, cloud-based service should be highly portable, as this would reduce the possibility of vendor lock-in.

- **Privacy:** [56] lists complexity of risk assessment in a cloud environment, emergence of new business models and their implications for consumer privacy, and achieving regulatory compliance as top challenges for maintaining privacy in cloud-based services. Before adopting any cloud-based services an organization must explore questions such as:

  - Where is the data located?

  - Where and how is the data replicated?
  - Who has the control over the data?
  - How will a CSP meet required legal and regulatory requirements for data storing, processing, and deleting?

- **Quality of Service:** QoS can be measured by performance, reliability, and availability offered by an application and by the platform or infrastructure that hosts it. Targeted QoS levels and associated economical penalties (in case) are specified in the SLA [1]. Based on these specifications CSPs can establish appropriate trade-offs between QoS targets and its respective operational costs.

- **Reliability:** Reliability is the probability that a system will function as expected over a period of time. Reliability, for example, can be measured using the Mean Time Between Failures (MTBF). The reliability of cloud-based services is very critical but hard to analyze due to its characteristics of large-scale service sharing, wide-area network, and heterogeneous software/hardware components and complicated interactions among them [26].

- **Scalability:** Scalability is the ability of the system to accommodate peak loads by adding resources (*e.g.,* VMs, storage space) either by making hardware stronger (scale up) or adding additional nodes (scale out). The ability of cloud-based services to be able to scale on-demand leads to cost savings too [45]. The only limiting factor in 100% scalability is the ability of applications to support scalability.

- **Service Response Time:** The end-to-end response time is an aggregated delay of the service time in addition to delays incurred at the network nodes and links [102]. A lower service response time will lead to higher QoS. This parameter, therefore, is an important factor that has to be included in SLAs so that expected performance is ensured from the side of CSPs.

Table 3.2: Technical Factors Overview

Technical Factors (Tn)	
Accessibility (T1) Availability (T3) Backup (T4)	Application Lifecycle Management (T2) • Patching • Upgrades
Complexity (T5) • Expectation Conformity • Flexibility • Frustration • Task Adequacy	Customization (T6) Data Access (T7) Data Loss (T8) Disaster Recovery (T9)
Fault Tolerance (T11) • Reactive • Proactive Functionality (T12)	Elastic Resourcing (T10) • Bandwidth • CPU Power • Number of VMs • Storage
Initial Migration and Data Transfer (T13)	Integration (T14)
Interoperability (T15) • Storage • Application • OS	Management and Maintenance of Identity Platform (T16) Management Authentication Platform (T17) Multi-tenancy (T18)
Portability (T20) • Data • Service • Functional	Network Quality (T19) • Bandwidth • Connectivity • Latency • Jitter
Privacy (T21)	Quality of Service (T22)
Reliability (T23)	Scalability (T24)
Service Response Time (T25)	Software Assurance (T26)
Security (T27) • Confidentiality • Integrity • Availability • Auditability • Multi-tenant Trust	Standards for API (T28) Trialability (T29)
Traceability and Audibility (T31) Vendor Lock-in (T32)	Usability (T30) • Application Launch Time • Graphics Agility • Simplicity • Learnability • Installability • Response Time
Workload Management (T33) • Classification • Capacity Planning • Performance Management • Configuration Management • Mission Criticality	Workload Utilization Ratio (T34) Multi Tenancy (T35)

- **Software Assurance:** For cloud-based services, software assurance is the likelihood that a cloud service will perform as expected and/or promised in the SLA [46]. It also accounts for trustworthiness (no exploitable vulnerabilities), predictable execution, and conformance to appropriate secure APIs to ensure interoperability in a cloud environment.

- **Security:** An IDC report reported that 75% of the respondents of the survey mentioned security as one of most important factor to be evaluated, while adopting cloud-based services [111]. This is of utmost importance for the public cloud, specifically when sensitive data is stored on cloud. As the provider has full access and control over the data, responsibility of data theft, loss, and adherence to legal and regulative guidelines for storing data has to be carefully evaluated.

- **Standards:** Cloud-based services urgently need a specific set of standards to which CSPs can adhere to. All of the organizations that participated in the interviews raised concerns about being locked-in with a specific CSP. Cloud services must be accessible through standardized mechanisms. This implies that adherence to standards should be applied throughout the technology stack, from the network layer up to the presentation layer [115]. While adopting cloud-based services in an organization it is crucial to avoid CSPs that are using vendor specific protocols, as it will become a stumbling block in terms of flexibility when applications and data are to be moved from one platform to another. Open Virtualization Format (OVF) standard provides a standard packaging format for software solutions based on virtual systems, which allows a user to move VMs from one CSP to another. However, it is very complicated to use, and might also not always include all the configuration, security, resource allocations, and uthorization settings.

- **Trialability:** To many cloud adopters, the ability to try and experiment with cloud systems is crucial [131]. It helps to set the right expectations of a service. It also reduces the risk of finding that the requirements are not fulfilled after committing to a CSP or a cloud-based service.

- **Traceability and Auditability:** Traceability and auditability refers to the extent till which usage and changes of a service and data can be tracked [87]. Traceability and auditability is not only relevant to ensure that the billing is correct, but is also relevant for legal compliance. The possibility of increased traceability and auditability of changes in information benefits CC adoption.

- **Usability:** Usability refers to the experience a user has with a cloud service. The easier a service is to learn and use, the faster an organization can adopt it. Usability can be measured using qualitative and quantitative feedback from its users with metrics such as application launch time, install-ability (ease of installing an application), simplicity (ease of using a system to achieve the desired objective), learnability (time and effort required to learn a service), and response time [46].

- **Vendor Lock-In:** As pointed out by every organization that participated in these case studies, vendor lock-in is an obstacle for a successful adoption of cloud-based services. It also has high negative impact in terms of cost and interoperability in cases when the service provider has to be switched. It highlights the need of common standards for APIs across cloud-service providers, so that interoperability is possible [7].

- **Workload Management:** Workload management is used to distribute tasks over resources to achieve optimal performance. It requires to carefully plan the capacity, performance and estimate the criticality of the task, and its corresponding resource and security configurations [115].

- **Workload Utilization Ratio:** The workload utilization ratio is the degree of usage of resources. This is often the case in traditional architectures where the demand vaires with time. With traditional systems, organizations need to install hardware based on peak requirements. This results in a poor workload utilization ratio, as resources that are sized to handle peak loads are under-utilized at off-peak times [115]. Public and multiple cloud models that allow for high scalability and sharing of resources with multiple users highly increase the workload utilization ratio.

3.2.2.2 Economical Factors

A key economic advantage of the cloud is its ability to address variability in resource utilization. By pooling resources and by sharing it with multiple users, variability is diversified and it evens out utilization patterns. The larger the pool of resources is, the smoother is the aggregate demand profile and the higher is the overall utilization rate. This also makes cloud-based services cheaper and CSPs can meet its end-user demands more efficiently [84]. The complete list of identified factors along with its relevance in decision making from economical perspective is listed in Table 3.3, and corresponding XML structuring is presented in Appendix A.

- **Billing and Metering of Resource Usage:** Alignment of IT resources with their cost can determine the profitability and allocation of cost per department or user. Identification of IT resource costs before and after their use along with what or who is consuming those resources is crucial for paying for ongoing support to keep the services available and maintained. The operation of cloud computing metering and billing is provided in some infrastructures (that is, the public infrastructure) and still required in private clouds built on enterprise application server infrastructures [97].

- **Carbon Footprint:** The adoption of Cloud Computing could lead to a 38 percent reduction in energy usage in the world's data centers by 2020 [98]. A study conducted in Lawrence Berkeley National Laboratory found out that "if all US business users shifted their email, productivity software, and Customer Relationship Management (CRM) to the cloud, the primary energy footprint these software applications might be reduced by as much as 87% or 36 Petajoules" [77]. This is equivalent to the electricity used by the city of Los Angeles each year (23 billion kilowatt-hours) [77]. This possibility of saving energy by moving IT infrastructure and data into cloud from in-house data centers, is a huge reason for the interviewed organizations also to adopt cloud-based services .

Table 3.3: Economical Factors Overview

Economical Factors (En)	
Billing and Metering of Resource Usage (E1)	Carbon Footprint (E2)
Cost (E3)	Capital Expenditures (CAPEX) (E4)
• License	Cost Flexibility (E5)
• Maintenance	Marginal Cost and Profit (E6)
• Migration	Migration Time (E7)
• Back-up	Return-of-Investment (ROI) (E8)
• Energy	Operational Expenditures (OPEX) (E9)
• Hardware	• Fixed Cost
• Future Requirements	• Variable Cost
• Performance	Total Cost of Ownership (TCO) (E10)
• Data Loss	• CAPEX
• Switching Providers	• OPEX
• Integration	Traceability and Audability (E11)
• System Administration Cost	• Data and application

- **Costs and Total Cost of Ownership (TCO):** In CC, multiple users can have their data and applications hosted on same set of servers. Users get the package of services as VMs. Therefore, VM is the unit of resources in Cloud-based services on which calculation of cost is done [71]. For using Cloud-based services, organization has to pay for resources (computing resources, storage, data IO transfer) as per the use, hence make cloud flexible in terms of cost. TCO is related to CAPEX and OPEX, as it includes all the costs of owning (subscribing and operating) a Cloud-based service. Reasons of cost in an on-premise solution include infrastructure, hardware, software, maintenance and support costs, which are already part of subscription cost in case of cloud-based services. Operating costs for cloud-based services include license cost that depends on number of users, and is fixed for the lifetime of subscription. Initial and any subsequent training of employees with respect to using and operating cloud-based services also add on to the operating cost. TCO also includes integration and customization cost, which is needed to migrate legacy systems to the Cloud. In future, due to any reason if an organization decides to switch CSP, there is a high associated cost due to lack of interoperability and portability.

- **Migration Time:** When large databases (with at least a few terabytes of data) are to be migrated to Cloud it is important to have the correct data migration strategy, have the appropriate tools, and most importantly use appropriate database features such as partitioning and compression. One of the major obstacles in migrating data is that of availability of only a small window of time and lack of system resources (*e.g.,* staging areas for data files) [69]. Higher migration time tends to be more costly, and would be accompanied with higher chances of data losses and inconsistency.

- **Return-of-Investment (ROI):** ROI is the ratio of the benefit of the investment against the cost of the investment, and therefore is related to TCO [86]. The Higher the ROI is, higher is the attractiveness of CC. It is dependent on business requirements, organizational maturity, regulatory requirements, benefits and costs associated with the cloud service that the organization will select. As CC not only lowers the costs but also shifts the high capital expenditure to operating expenditure, ROI increases with the adoption of CC. However, one crucial point, is that of consideration of any unexpected event (*e.g.,* data loss, service outage). These events can drastically reduce the ROI and then only after certain interval in time will the ROI gain momentum again.

- **Traceability and Audability:** A traceability platform for cloud-based services overcomes non-transparency concerns by reproducing and displaying the chain of events from log information indicating human operations, file transfers, and process activity. Auditability and compliance features should be understood and agreed upon before before cloud-based services are adopted in an organization.

3.2.2.3 **Organizational Factors**

Understanding the significance and extent of impact on management and operation of IT infrastructure due to adoption of cloud-based services in an organization is a challenge. Therefore, it is crucial to identify factors, which measure or qualify this impact. CC majorly changes the way IT infrastructure (data and applications) is being accessed, stored, and controlled. Therefore, some of the major changes are in terms of transparency, compliance, and access control over applications and data. This in-turn changes the role and management of personnel within the organization [9]. The complete list of identified organizational factors and their relevance is shown in Table 3.4, and corresponding XML structuring is presented in Appendix A.

- **Business Flexibility and Agility:** Business flexibility and agility can be interpreted in different ways: It can refer to automated process through which cloud computing simplifies provisioning and de-provisioning of the resources, or increased pace of innovation and development of services as per the need. CC can also enable “agile addressing of new markets and offerings” [16] for organizations that use the cloud to bring their own services to end customers. In addition, it also allows for better integration with existing business partners and customers as it helps to share information and business processes across value chains and geographies [16].

Table 3.4: Organizational Factors Overview

<table>
<tr><th colspan="2">Organizational Factors (On)</th></tr>
<tr><td>Business Flexibility and Agility (O1)</td><td rowspan="3">Collaboration (O2)
• Intra-Company
• Inter-Company</td></tr>
<tr><td>Control (O3)</td></tr>
<tr><td rowspan="3">Legal and Regulative Compliance (O4)
• Location of Data
• Ownership of Data
• Access Control</td></tr>
<tr><td>Location (O5)</td></tr>
<tr><td rowspan="2">Organizational Compatibility (O6)
• IT Competence of Employees
• Management Competence
• Process Redesign
• Rigidness of Organization
• Size of Organization</td></tr>
<tr><td rowspan="2">Relational (O7)
• Competition in Market
• Contracts and SLAs
• Skills and Expertise of the CSP
• Transparency of CSP
• Trust Towards Cloud Provider</td></tr>
<tr><td></td></tr>
</table>

- **Collaboration:** Collaboration is the process of working together to achieve a common goal. For example, files can be uploaded to central storage so that co-authoring is possible. Collaboration can either be within an organization or between different organizations. CC can increase collaborative process, as projects and documents are centrally available in the cloud and accessible to every legitimate user. Collaboration can both be intra- or inter-company [16]. Multiple organizations working along the same value-chain, but with high security concerns, can choose community clouds. Community clouds allow an organization to have a cloud environment that is customizable as per their security and resource demands with reduced cost and increased collaboration.

- **Control:** Before moving the data and applications to cloud-based services, it is important for potential adopters to understand the concept of control over the cloud-based services [87]. It entails questions such as:

  – Who is accountable for being in control of a cloud-based service?

  - How is the control over cloud-based services in terms of its operation and use implemented?
  - When, how, and to what components of the cloud-based services is the control applicable?

  Answers to these questions can vary depending on if its data or functionality of an application that is under discussion with respect to control and access privileges.

- **Legal and Regulative Compliance:** This section discusses various requirements from legal and regulatory bodies (across different parts of the world), which CSPs and organizations have to adhere to. The current EU Data Protection Directive 95/46/EC (EU DPD) [34] is the framework applicable for all members of the EU. It is targeted to protect the privacy of all personal data that is processed for or about citizens of the EU. The General Data Protection Regulation (EU GDPR) [35], which exists as draft since 2012, is expected to supersede the EU DPD. As a regulation, unlike a directive, it is valid, self-executing and applies to all members of the EU. Therefore, it does not require implementation on a national level by the members. The most noticeable difference between the EU DPD and EU GDPR is the change of instrument. The regulation will "contribute to having one single law applicable throughout Europe", enabling greater consistency in Europe [17]. This section will discuss both the implications of the EU DPD, which other countries legislations, such as Australia, Canada and Argentina also comply with (and Switzerland partially), and changes that were made in the working copy of the EU GDPR.

  - **Technical Safeguards:** Cloud-based services especially in the case of public clouds, are often accessible from everywhere all the time. While this increases the agility and flexibility of users, it also introduces the need for identity management and authentication to comply with the data security principles and laws [20].

- **Proper Exit Plan, Data Erasure and Data Portability:** Data processors are responsible that they comply with the collection limitation (limits to the collection of personal data), use limitation (data should not be disclosed, made available or otherwise used for purposes that are not in accordance with the purpose specified), and that data subjects can have their data deleted permanently if needed. It is essential, that a proper exit plan is agreed upon and it is ensured that data is deleted on termination of any contracts. Under the EU GDPR it is also required, that data subjects can receive a copy of data stored in a common format, hence facilitating data portability and interoperability [20].
- **Limitations on the Data Use in the Cloud:** Public CSPs might receive data from several of their customers on data subjects, in some cases the data subjects might use them directly. This leaves CSPs in a position, where they can combine data of different sources on data subjects. However, this is prohibited by the use limitation principle and laws derived from it. Data processors should include limitations on how data is to be used by CSPs in the contract [20].
- **Formal Data Breach Management and Notification Arrangements:** Data subjects must be informed on data breaches. Plans for all eventualities of data breaches should be in place from the very beginning, ensuring disaster recovery [20].
- **Location and Cross-border Data Flow:** CSPs store data in different jurisdictions (countries), in order to facilitate access of data by the user from anywhere, and that too at a cheap associated cost (e.g., lower energy cost). Also,

data might be replicated at different locations to ensure there is no downtime. However, this has various legal and regulatory implications, specifically for sensitive data. As the data crosses the borders the applicable law is no longer fixed or easily identifiable. The EU GDPR also clarifies that a CSP will fall under the EU legislation when they offer services to data subjects in the EU or monitor the behavior of data subjects within the EU. In addition, to ensure scalability and elasticity CSPs might subcontract third-party infrastructure provider to provide additional resources. According to EU GDPR, data owners must be informed about any such data movements. However, there is no way to ensure that the CSPs are transparent in this regard. This in turn safeguards the CSPs in case of of data breach or misuse, as the data owners can not hold third-party liable due to missing information of how and where data breach happened.

- **Contracts and Service Level Agreements:** Requirements such as that of availability, response time, or latency can be very critical for organizations. These factors and their lower and upper thresholds are essential part of a SLA to ensure that CSP does provide the promised and/or guaranteed performance, and liability in case of future failure(s) is clearly identified. The penalties and liabilities are included in the section of warranties and remedies of SLA that describe the consequences of when the service and quality levels agreed upon are not met. This not only includes fines but also the possibility of terminating service (without cancellation period) [12]. This section should also, however, include third party claims, remedies for breaches, and the exclusion of force majeure [62]. SLAs also need to specify following: (a) definition of services, (b) performance management, (c) security, (d) disaster recovery and business continuity, (e) termination of the contract conditions, (f) subcontractors, applicable law, and (g) place of jurisdiction. All these parameters contribute to the compliance evaluation of cloud-based services to legal and regulatory requirements. Also according to the privacy guidelines by the Organization for Economic Co-operation and Development (OECD) organizations have the right to ask for the disclosure if CSPs have any data relating to the individual, and a copy of the information within reasonable time. Data subjects also have the right to have "the data erased, rectified, completed or amended as appropriate" [20]. Data owners must therefore ensure that CSPs can fulfill these obligations.

– **Safe Harbor Agreement:** Unlike in the EU, USA does not have a comprehensive data protection law, as none of the authorities have the power for a national privacy law. As for federated laws, the Privacy Act of 1974 regulates the collection and usage of data that contains personal information. But this is valid only for personal data of US citizens [65]. As all the states in USA can have their own laws, there are many scattered laws that can apply to Cloud-based services. Therefore, it can be concluded that there are "enormous differences" [64] between the regulation in the European Union and the United States [64], [4], [53]. Even though the level of regulation in the EU and the US varies greatly, the Safe Harbor Agreement [32] allowed personal data transmission between the EU and the US till October 2015. The US counterpart had to self-assess if they adhere to EU DPD and register with the Department of Commerce. Once this was completed, the US company was seen as safe harbor and personal data was allowed to be transferred as within the EU. While the recent revelations of Edward Snowden has led to discussion if the transmission is still legal in light of the US surveillance framework, in practice it remained the easiest solution for CSPs located in the US till October 2015 [107]. However, after the complaint of Maximillian Schrems, an Austrian citizen, EU Commission has declared US Safe Harbour as invalid, leading to examining the security of data being transferred to United States that belong to European subscribers [37]. On February 2, 2016 the EU commission and the USA agreed on a new framework for transatlantic data flows: The EU-US Privacy Shield. The new arrangement includes commitments by the USA that possibilities under USA law for public authorities to access personal data transferred under the new arrangement will be subject to clear conditions, limitations and oversight, preventing generalized access [33].

- **Organizational Compatibility:** Besides the adjustment in technical, economical, and legal domain, it is crucial to analyze how the current IT work force needs to change with the adoption of cloud-based services. Based on the interviews with the organizations, it was found that if there is no workforce enablement in place, the cloud-based services might fail to give positive results. This enablement process includes providing technical know-how, integration know-how, discussion of new tasks and responsibilities, and restructuring of the organization [9]. Potential adopters may face organizational inertia as shifting to a Cloud environment may change the role of IT departments in the organization [9]. Lastly, business processes and workflows might have to be redesigned within an organization with the adoption of cloud-based services. Therefore, it is crucial that the integration with the existing processes, applications, and legacy infrastructure is done with utmost diligence.

- **Relational:** This factor includes all the factors that influence the relation of a CSP and the potential adopter of cloud-based services. One important factor is that of trust. It describes the expectations from the side of organization from a CSP that it will "perform as expected and treat the client organization fairly and reasonably" [47]. The level of transparency maintained by CSPs about privacy, security, and data storage policies also influences trust. These policies and corresponding guarantees should also be part of the SLAs, too.

3.2.3 Interrelations of Factors

The factors outlined above can have numerous and complex use case specific interrelations based on expectations of an organization from a cloud-based service. Identifying interrelations between the factors are critical to decision making - without them the list of factors is just a taxonomy of terms with very broad semantics since they lack their associated context. These interrelations are discussed in terms of their hierarchy ("is parent of"), and their influence over other factor(s) ("influences"), as shown in Figure 3.3. The former either signifies a relationship between category of factors (technical, economical, or organizational) and the factor itself, or a relationship between a factor (*e.g.,* network quality) and its sub-factors (*e.g.,* connectivity). The latter of the two can signify if two factors complement or contradict each other. Decisions involving contradictory factors inherently require trading off one factor against another.

In addition, factors can also be compared to each other for relatively prioritizing all the factors. An organization prioritizes factors initially from the perspective of how valuable each one is to them. This analysis would include cost, technical risk, or organizational impact associated with a specific factor. The task of assigning priorities to all the factors is achieved by using 7 points Likert Scale, which is the sum of responses on several Likert items [73]. A Likert item can be a multiple choice question

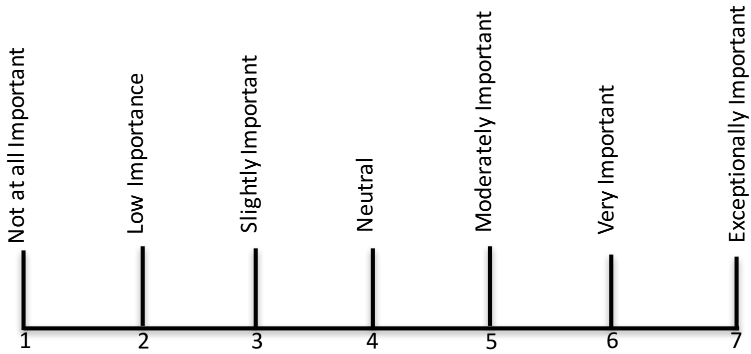


Figure 3.2: Likert Scale for Question: How Important is Factor 1? [73]

that the decision maker(s) are asked. By selecting one of the options (mostly associated with level of agreement/disagreement), the decision maker can rank the factors. The granularity of the scale can be altered as per the need. A Likert scale assumes that the variation in values is linear, *i.e.,* on a continuum from strongly agree to strongly disagree, and makes the assumption that attitudes can be measured [2]. At first it seems quite regressive as each factor should be analyzed on the scale but with regular use the approach can be implemented comfortably. It is conducted by associating numeric value within the range of 1-7 to the qualitative answer of the question of how important is each factor, as shown in Figure 3.2. If there is a group of decision makers answering these questions, the final priorities can be assigned using a median or mode.

Following points are important to note before details of these interrelations are discussed:

- The grouping of these interrelations is based on the discussion with the organizations that highlighted some of the most important interdependencies between numerous factors. The aim here is to analyze and model only those interrelations in detail rather than modeling a complicated web of all interrelated factors.

- These interrelations are very specific to use cases under consideration. So it is impossible to generalize and complete this modeling of interrelations in full. For example, one or more factors can have multiple occurrences in several interrelations grouping thereby interconnecting different groups conceptually.

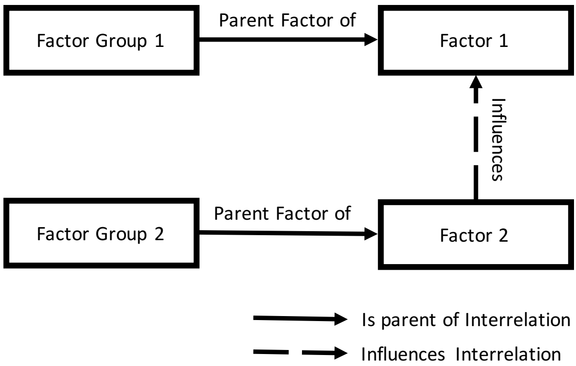


Figure 3.3: Legend for Interrelations of Factors

All interrelations and their associated impacts are scenario specific and are valid only for the time frame or instance under consideration. Hence, the factor of time influences all the factors analyzed in this chapter. For example, if at the current instance there is no data loss associated with the deployed cloud-based services, all security policies and associated cost will be at an acceptable level from the organization's perspective. However, if at the next instance there is a data leakage or loss experienced, the situation would change as now measures would have to be taken to safeguard the data with stricter policies. Time specific modeling for decision making requires identification and analysis of all possible eventualities and their time specific values for performance of all alternatives. As this modeling of factors in conjunction with time can be very dynamic, it is excluded from the decision making methodology developed within this thesis. However, Chapter 5 briefly evaluates influence of time over interrelated factors using time-based graphs. Detailed analysis and inclusion of dynamic changes in values of factors are part of future work, and are discussed in Chapter 6.

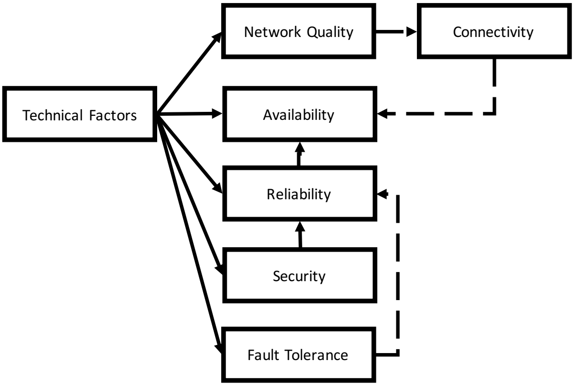


Figure 3.4: Interrelations Affecting Availability

Availability: With the geographically distributed systems of servers and storage, there are many factors (shown in Figure 3.4) that can effect and change the promised availability by a CSP. Once availability of Cloud-based service is affected, the after-effects on the organization can be manifold too. Therefore, CSPs are expected to take every possible measure to decrease the number of outages. For example, to ensure high availability (1) all data centers can be connected to ensure that they are synchronously mirrored, (2) auto-scaling of the application can be set so that dynamic traffic demands can be handled, and (3) redundant locations for storing data can be increased. In addition, in building a highly reliable infrastructure, redesigning of network, storage, and server play a crucial role. Even when there is a security issue, CSPs are required to take measures to provide business continuity for the organizations. If high availability is ensured it reduces associated costs of data loss and the need for switching to a different CSP. Availability is also dependent on network quality. With a stable network speed any possibility of outage can reduce considerably. However, since availability is dependent on several other factors (as explained above), an increase in network quality alone can not guarantee 100% availability.

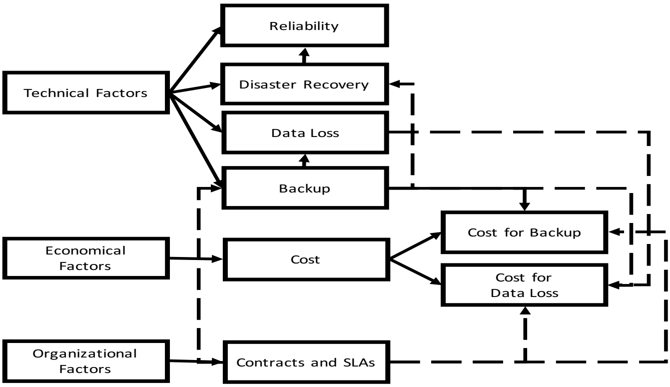


Figure 3.5: Interrelations Affecting Backups

Backups: In order to ensure that the information is not lost, CSPs often do data backup. However, as shown in Figure 3.5, this adds to the expenses of the organization. Therefore, SLAs need to specify all relevant parameters, so that liability, costs, and consequences in case of any failure are known in advance. Cost and backup can be positively related to each other if there is no external influence (*e.g.,* data loss). In other words, increase in backup will imply a higher cost for organization, and if a CSP does not offer backup or decreases the backup (*e.g.,* frequency of backups), cost will decrease for the organization. However, if there is no back up in place data loss can have huge cost implications for an organization. This additional cost is associated not only with disaster recovery mechanisms that have to be applied (recovering lost data can require high investments), but also with the loss of potential future revenues due to unavailability of service.

Return of Investment: ROI is related to CAPEX, OPEX, and TCO. The interrelations are shown in Figure 3.6. ROI also includes any profits or losses associated with cloud-based service. Therefore, with increased business agility and flexibility new market opportunities can lead to additional profit, therefore increasing ROI of CC. However, any data loss can be associated with high costs thereby adversely affecting ROI. Cloud Computing has an impact on the margin through cost reduction and through economies of scale to make more use of the same resources. That implies ROI is also affected by cost-effectiveness of Cloud workload utilization.

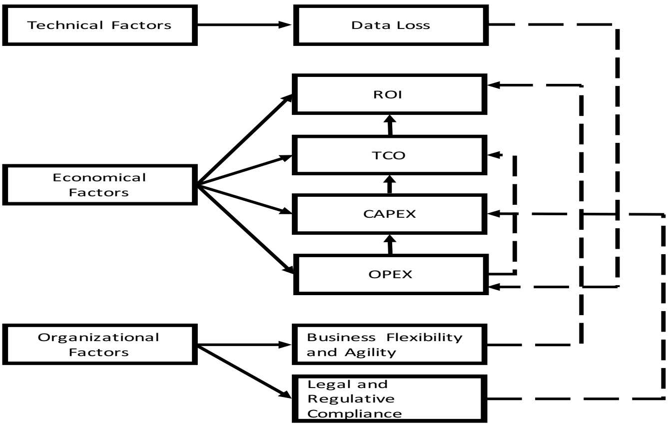


Figure 3.6: Interrelations Affecting ROI

Migration: Migrating applications or data to Cloud-based services involve high efforts and time from the side of organization. The higher the time and the resources that have to be spent on migration, the higher is the cost associated with it. Also, a longer migration time introduces the risk of inconsistencies in data. As identified in [118] and [10], irrespective of the deployment model, there are several tasks – Training and Learning, Installation and Configuration, Code Modification, and (Performance) Testing – that add to the total migration complexity and cost. In addition, when the applications and data are migrated to Cloud-based service, security becomes a critical factor. To securely migrate data to cloud environment efficient methods have to be investigated and implemented so that there is no possibility of unauthorized access.

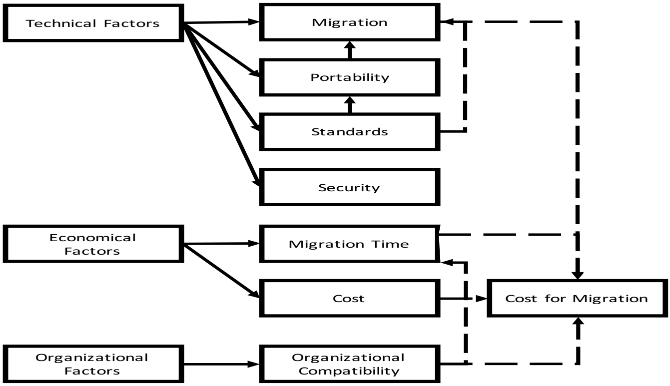


Figure 3.7: Interrelations Affecting Migration

In addition, CSPs use proprietary solutions to provide cloud-based services. This makes migration of data and applications from one Cloud-based service to another a complex and near to impossible task (leading to vendor lock-in). Therefore, there is a need of common standards and common service descriptions from CSPs, so that cloud-based services are interoperable and portable. Another hindrance towards easy migration is the unwillingness and non-adaptability of organization to change while adopting Cloud-based services. There are high chances that such a migration requires redesigning of the existing organizational processes, restructuring of organization, and additional training of the employees. Therefore, the organization should be open to change and to adopt and learn new technology. All these factors, are therefore, interrelated to migration as depicted in Figure 3.7.

Vendor Lock-in: The lack of common Open API leads to CSPs implementing Cloud-based services with its own proprietary technology. This causes implementation differences between two Cloud-based services in terms of: (1) Operating systems and hypervisors, (2) network services and architecture that includes network addressing, firewalls, routers, and (3) security policies including firewalls, access and data share policies. This in turn leads to a situation of vendor lock-in as a user can not switch the CSPs with minimalistic efforts, cost, and time. Therefore, common prototyping protocols, formats, and common mechanisms are needed that can be adopted by multiple CSPs to support interoperability [14].

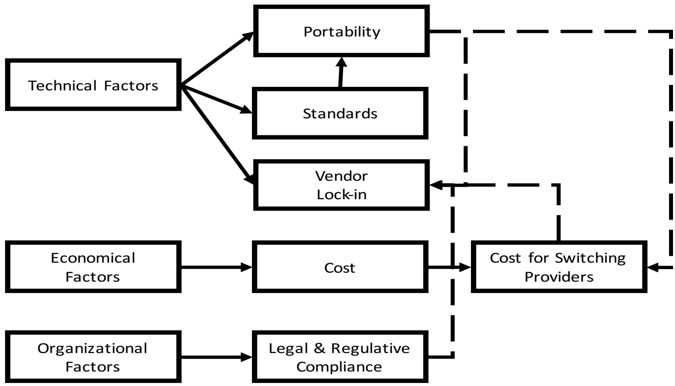


Figure 3.8: Interrelations Affecting Vendor Lock-in

If in future CC undergoes through a situation where there is too little competition, and there is abusive behavior of CSPs due to monopoly, regulators might interfere. This is due to the goal of competition/anti-trust laws to protect the customers [64]. Article 102 of the Treaty on the Functioning of the European Union (TFEU) states that "any abuse (...) undertaking of a dominant position (...) shall be prohibited" [36] . This includes situations where CSPs are excluded from competing for customers of dominant CSPs. However, the competition law is only partially applicable for implications that exist in CC. Not only the behavior has to be abusive, but a CSP must also be in a dominant position. While there is no clear demarcation where a CSP is considered to be dominant, generally a market share that is above 40% is considered problematic [105]. Another factor that is considered while deciding if competition law is applicable is that of market entry barriers [127]. The current situation in CC, however, has no clear market leader. Competition between providers (including Google, Microsoft, Amazon, Salesforce) is fierce [105] and it is unlikely that one of these providers will find themselves in a dominant situation within the foreseeable future. Furthermore, while entry barriers exist such as that of high initial costs, they cannot be considered “insurmountable” [105]. Therefore, even though the lack of standards and lack of data portability and full interoperability of cloud-based services, can lead to disadvantages for customers, there is no evidence that there exists a situation that would call for an intervention from competitive law. However, if the leading CSP act in a way to specifically shield their services, it might become a case for competition law. Competition laws should encourage open cloud systems, promoting open standards, and monitor the market carefully [127]. Therefore, if there are no common standards or if this difference between different cloud services increases, the chances that two different cloud based solutions are interoperable will further decrease. This in turn will lead to higher risk of vendor lock-in and vice versa. One of the major motivations for CSPs to increase standards in CC can be that of optimizing workload and their utilization ratio. This is because, higher is the ease and possibility of cloud federations or bundling up of resources, better will be the economies of scale. However, CSPs that cannot offer competitive prices and services, risk loosing all the current customers and being forced out of business. The only reason, as explained above, where the vendor lock-in might completely vanish is due to a possible interference of regulators.

3.3 Chapter Summary

It can be concluded to adopt a new technology in an organization careful coordination and evaluation of technology from various aspects is necessary. Therefore, this chapter has identified and analyzed 102 factors from technical, economical, and organizational domains and their interrelations that effect the decision of adopting cloud-based services. These factors have been analyzed with extensive survey with 17 organizations and literature review to ensure that these factors are complete, and are applicable to decisions of adopting cloud-based services in an organization. The taxonomy of factors developed in this chapter will be provided as a guideline to any organization that uses TrAdeCIS for evaluating cloud-based services. This evaluation can be done on the basis of a capability of CSPs to fulfill the expected level of performance for each of these factors, thereby aiding organizations to select the best alternative as per IT requirements and objectives. Various attributes like tendency, relationship or grouping are integrated in the taxonomy in order to reason about factor characteristics and facilitate efficient computation of ranking for cloud-based services. Furthermore, this taxonomy can be used to ensure that all relevant and critical factors are specified in the SLA with a guaranteed level of expected performance.

4

Trade-off-based Decision for the Adoption of Cloud-based Services

The decision of adopting cloud-based services is complex owing to possibility of selecting the best suited cloud-based service from several available alternatives. Driven by the motivation outlined and the complexity identified to develop a quantified decision methodology for adopting a new technology, this chapter develops, implements, and analyzes a quantified Trade-offs-based Adoption methodology for Cloud-based Infrastructures and Services (TrAdeCIS) to facilitate such decision making. From design perspective the methodology of TrAdeCIS comprises of three major components. These cover requirement modeling, alternative ranking, and trade-offs establishment. The approach taken with these three components (and the respective set of sub-steps in each of these components) reflects the complexity and relevance of a successful decision. As important as the identification of requirements is, it is the modeling of both quantitative and qualitative factors, alternative ranking, and trade-offs establishment that determine the overall significance of the developed methodology of TrAdeCIS within this thesis. Once the most optimal alternative is identified using TrAdeCIS, this chapter develops and applies an impact analysis methodology for predicting the impact this alternative will have on an organization from technical, economical, and organizational perspective.

4.1 Design of TrAdeCIS

From a design point of view TrAdeCIS comprises of following three major components as shown in Figure 4.1 and defined below:

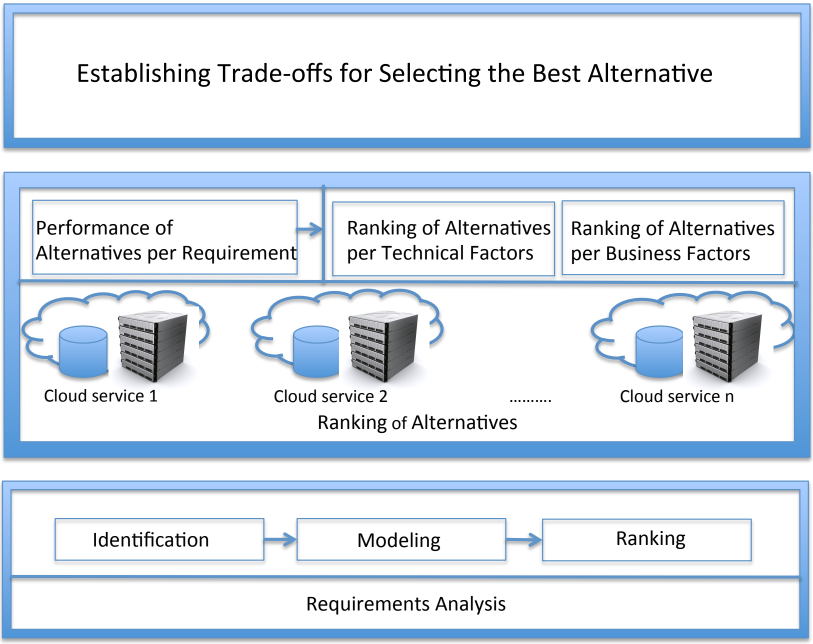


Figure 4.1: Components of TrAdeCIS

- **Requirements Analysis:** The first component of TrADeCIS consists of identification of requirements or expectations of organization from adopting cloud-based services. These requirements are the relevant factors based on which several available alternatives will have to evaluated and ranked. In order to do so it is important to model interrelations, including any conflicting interdependencies of all relevant factors. This thesis has built a taxonomy of factors and their interrelations from technical, economical, and organizational domains in Chapter 3. The decision maker can use this taxonomy and select relevant factors as per their use case while making decision of selecting cloud based-services using TrAdeCIS.

- **Ranking of Alternatives:** To make decisions using MADA algorithms, relative ranking of alternatives per requirement or factor is required as an input. As factors can have values in different units (*e.g.,* boolean, string, set, numeric), a method is required to support relative ranking for both qualitative and quantitative factors. TrAdeCIS facilitates relative ranking of alternatives by following means:
  - If the factor is measurable, *i.e.,* have numeric values, the performance values per factor for each alternative can be directly entered as the input. This is because TrAdeCIS normalizes these values, and therefore their different units and varied range of values do not alter the decision. This thesis takes values from Harmony Inc [22] that is a platform to measure and monitor technical and corresponding economical values for cloud-based services.
  - For qualitative factors such as that of legal and regulative constraints, this thesis has developed a method to rank alternatives as presented in the Section 4.1.1.
- **Establishing Trade-offs for Selecting the Best Alternative:** The decision of adopting cloud-based services is associated with trade-offs of requirements and business objectives of an organization. For example, trade-off can be between performance and security of cloud-based services and its associated cost. Higher the functionalities expected from the

cloud-based services, higher is the cost. However, an organization would aim to reduce associated costs. The positives of moving to cloud can be in terms of reduced in-house management and operation hassle, but on the other hand when the data is outsourced downside is the unknown location of data storage. Therefore, the last step of TrAdeCIS establishes trade-offs so that the best technical solution is selected at an acceptable return value (measured with economical and organizational factors).

4.1.1 Legal and Regulative Requirements Modeling

The laws and regulations are complex, and can be interpreted in different ways based on the specific scenario. These regulations and their interrelations to various technical and economical requirements are modeled in this thesis using Goal-oriented Requirement Language (GRL). GRL is a modeling language used in system development to support goal-oriented modeling and includes requirements, specifically non-functional requirements [57]. A number of approaches for modeling requirements exist from conceptual entity-relationship modeling, to structured, object-oriented, use case and goal-oriented approaches [57]. Goal-oriented approach is well suited to analyze non-functional requirements and the evaluation of alternatives whereas other approaches tend to focus more on analyzing requirements in the software development cycle with a focus on traceability between requirements and implementation. GRL supports qualitative and quantitative attributes, and allows to break large goals to be analyzed into small, realizable goals [88]. Therefore, for the modeling of qualitative factors such as that of legal and regulative requirements within the scope of TrAdeCIS, GRL is most appropriate language. The syntax of GRL is introduced in Figure 4.2. These GRL graphs are generated using jUCMNav v6.0.0, an open source Eclipse plug-in [122]. Definitions and relevance of basic elements and relationships of GRL notation that will be used within this thesis are as follows:

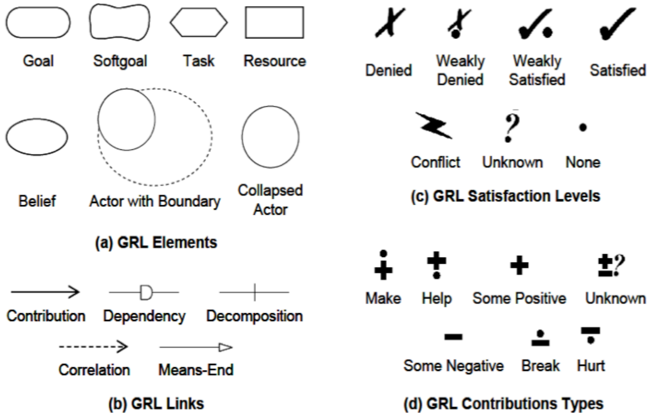


Figure 4.2: Legend for GRL Graphs [6]

- Goal: It represents the condition or state that is to be achieved with respect to functional requirements.

- Soft Goal: It represents non-functional requirements that can not be quantified. These elements are used to model the qualitative factors that influence the decision of adopting cloud-based services.

- Task: This represents various operational methods through which a goal or soft goal can be achieved. This element is used to model all the tasks that are to be completed in order to fulfill a goal or sub-goal.

- Resource: In order to be completed soft goals, goals, and tasks may require resources to be available.

- GRL Links: They are used to connect elements in a structural relationships. For example, a decomposition link allows an element to be sub-divided into two or more elements. AND, IOR, or XOR are types of supported decompositions.

- GRL Satisfaction Levels: These satisfaction values can be qualitative or quantitative and they capture contextual or future situations related to various alternatives, and are propagated to the goals and sub goals through GRL links. These elements also help in evaluating degree to which a sub goal or a goal is fulfilled.

- GRL Contribution Types: These indicate desired impacts of one element on another element. These elements can be used to model all the interrelations that might exist between any factor, tasks, resources, sub goals, or goals.

This thesis models qualitative factors within the scope of legal and regulative compliance using GRL graphs as shown below:

Data Storage and Deletion: Moving and storing data in the cloud means that in certain cases data will be moved outside the direct control of the organization. Therefore, an organization needs to evaluate a CSP with respect to adherence to security and privacy laws. According the European Data Protection Directive (DPD), a CSP has to abide with the local laws of the region where the server is located [34]. This implies that a CSP from any country, say the United States of America, who hosts the data on a server located in an EU member state, has to abide by the laws of the EU member state for transferring data. DPD introduces two responsibilities with the role of a data controller and a data processor. The EU Directive's rules on data protection states that the location of the data controller determines the national law applicable for data processing, as he is liable for data protection violations. Only in cases where a user modifies the data without the involvement of a CSP, he becomes the controller as well. In case of multiple locations, the responsibility of data controller can be on the CSP and/or the Infrastructure Provider (InP). As the exact location for data storage is not known, it complicates data protection, specifically in terms of personal access and deletion rights. When the data is transferred to multiple jurisdictions, the applicable law is still that of the data controller. Only in case of federated clouds, when the CSP is not in a member state, but the InP is located in the member state, the applicable law is that of the InP, even when it is just processing the data [61], [65].

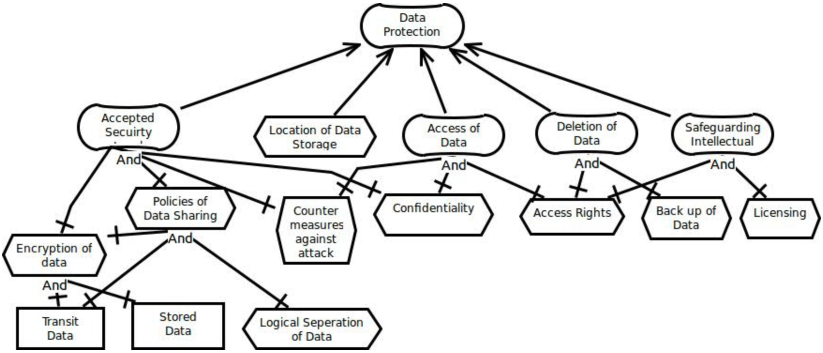


Figure 4.3: GRL Graph for Data Protection Compliance [40]

During the negotiation of a contract with a CSP, customers also have to be aware of licensing terms, intellectual property rights, indemnities and protection, or content access rights to the service provider. Data security also has to be taken into consideration from the CSP s side. It includes encrypting the data as well as applying correct policies for data sharing. In addition, resource management and allocation algorithms have to be secure. Organizations must have a right to audit security control within SLAs with the CSP, so that they can ensure security of a system that is not directly under their control. Also, cloud customers can review, if the application of encryption is mandatory by the jurisdiction of the CSP [104].

This thesis modeled all these requirements using GRL graph, as shown in Figure 4.3. The top-level soft goal is that of compliance to data protection requirements. These requirements can be regulatory in nature or driven from the side of the organization. Following soft goals and tasks contribute towards the satisfaction of the soft goal of data protection :

- Accepted Level of Security: Three tasks are to completed to fulfill this goal. Each of them is linked through AND contribution links toward the satisfaction of this soft goal. These tasks are:
  - Encryption of data: This task is applicable to resources of "Data in Transit" and "Stored Data". This means both of these data must be encrypted to satisfy the soft goal of encryption of data.
  - Policies of data sharing: This is decomposed in tasks of "Encryption of data" and "Logical separation of data". The latter of the two entails separation of data both at logical and hardware level to ensure that only legitimate access of data is allowed and possible. These elements are also linked through an AND link.
  - Counter-measures against attacks: As the data is in control of a third party and can be in transit, too, it can be susceptible to various attacks. Examples of these attacks are XML signature wrapping attacks on Web services [24]. Therefore, CSP must ensure that appropriate counter-measures against such attacks are in place.
  - Confidentiality: In order to implement confidentiality, a CSP needs to implement access control rights. These rights can be based on roles, IP addresses, or domains. Confidentiality also includes encryption of data, for example, by symmetric or asymmetric methods.
- Location of Stored Data: The location of the data controller *i.e.,* the CSP decides the applicable jurisdiction in case of any conflicts. Also, according to DPD, the data of member states shall remain in the member states. Therefore, a CSP must also fulfill such constraints in terms of location of data storage.
- Access of Data: This soft goal is decomposed into the following tasks toward the satisfaction of this soft goal:

  - Confidentiality: This task is same the task of confidentiality described within accepted level of security.
  - Counter-measures against attacks: This task is similar to that as explained in the soft goal of “Accepted Level of Security”.
  - Access Rights: The SP shall provide different levels of access rights as per requirement of an organization. This ensures that only authorized users have access to the data.

- Deletion of Data: The contract shall specify how long it takes to delete the data from servers of the CSP, once the contract ends. Initially the data is only marked for deletion by the CSP. The actual deletion happens at a later stage, which might be after months. This is specifically important in case of sensitive data being stored in the cloud. It is decomposed into tasks of “Backup of Data” and “Access Rights”

  - Backup of data: As the data stored on the cloud is susceptible to data loss and leakage, a CSP must provide data backup. This can be done with the help of data archiving, online backup, on-premise back up, or disaster recovery solutions.

- Safeguarding Intellectual Property:

  - Licensing: CSP must provide appropriate licenses when a service is provisioned to an organization. This would enable an organization to legally use the provisioned service without committing copyright infringement.
  - Access Rights: As CSP is liable for taking down any offensive or defamatory content, it will try to have content license from the cloud customers. Organizations must have a condition in SLAs pertaining to indemnity loss caused due to loss or deletion of data while accessing or moving it.

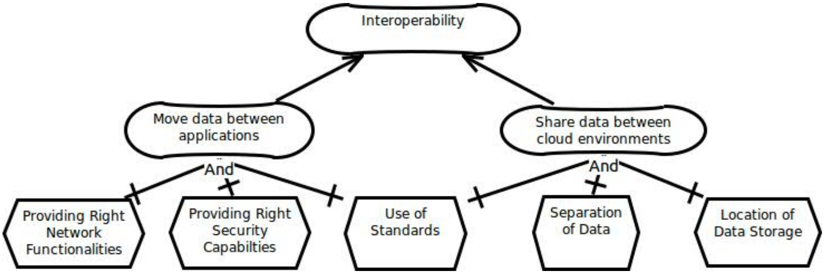


Figure 4.4: GRL Graph for Interoperability [40]

Interoperability: It stands for multiple things as that of: (1) Ability of applications to move from one environment to next, and (2) applications being able to share data that is hosted on different cloud environment. In other words, interoperability means different cloud providers can exchange data without a data schema or format translation, and dependency across APIs. As a common standard does not exist, an organization has a risk of facing vendor-lock in. When the application or data is to be moved between clouds (within the same or different CSPs), following key challenges have to be considered:

- Setting up the network and security to match capabilities provided by the source cloud-based service.
- Handling data movement and encryption on the data in transit.
- Checking security policies and access rights of resources provided by the CSP.

When the data or application is moved from one CSP to another, the data format (including the extent and semantics) has to remain the same. Also in case of moving applications the code also has to run on the new service, and interface considerations have to be taken into account. It is important that a CSP includes the following points in its SLAs:

- Use of standard APIs, data formats, and well defined services.

- For PaaS (Platform-as-a-Service) the application environment is based on open technologies.
- For IaaS (Infrastructure-as-a-Service), broadly accepted application formats packaging formats such as OVF for images.

Therefore, in terms of GRL graph this thesis modeled the top-level soft goal, as shown in Figure 4.4, as that of interoperability. This is contributed by an OR contribution link, from the following sub-goals:

- Move Data Between Different Applications: This is a sub-goal that is fulfilled by following tasks:
  - Standards: A Hypervisor is a piece of computer software, firmware, or hardware that creates and runs virtual machines. Hypervisors can be different between different IaaS providers. However, if the user decides to change the hypervisor special tools are to be used to convert to another hypervisor. Another solution is that of the OVF. Therefore, an organization must take into account the data format used by a CSP, if an organization foresees a possibility to share data between applications. Thus, the CSP can make applications interoperable by selecting platforms that support standardized tools and applications. However, a trade-off of standard APIs in case of PaaS is that it is more portable but it offers less control [11].
  - Security capabilities: The target CSP must be able to set up the security settings similar to that provided by the source cloud. Also, the source CSP must ensure that the data is encrypted during the transit.
  - Network capabilities: The target CSP must be able to match the network capabilities provided by the source cloud.
- Share Data between Different Cloud Environment:

– Separation of data: As data is stored alongside with data from other organizations, it is to be properly separated by the CSP to ensure secured storage of data. Data can be either logically or physically separated. This is important due to threat of loss, unauthentic access, and reliability issues.

– Standards: This is same as mentioned in previous sub goal of "Move Data between Different Applications".

– Storage location: In case of a federated cloud, the question of location is very unclear as there are multiple locations at which data can be stored. As mentioned before, the applicable jurisdiction in case of any conflicts is decided based on the location of the data controller, who is the CSP. Therefore, knowing location is an advantage for cloud customer.

– Licensing: Some CSP may not allow in house software licenses to be migrated to their environment and may require new licenses being bought by them to be deployed. The precise licensing requirements for third party softwares that are required by applications/services should be evaluated upfront for each alternative.

Ranking of alternatives, based on GRL graphs, is based on the fulfillment of GRL elements by each alternative. Higher the completion of goals and soft goals, higher will be ranking of that alternative will be. So for each alternative solution it has to be identified how many soft goals are fulfilled. Also, each soft goal can have different priority, depending on the requirements and objectives of the organization. If a sub goal is (not) completed SG_i is equal to *1(0)*, where $i \in [1, n]$, n is the total number of sub-goals. And priority of each soft-goal is given P_i. Therefore the final ranking of each alternative per factor R_f is given by:

$$R_f = SG_1.P_1 + SG_2.P_2 + SG_3.P_3 + SG_n.P_n \tag{4.1}$$

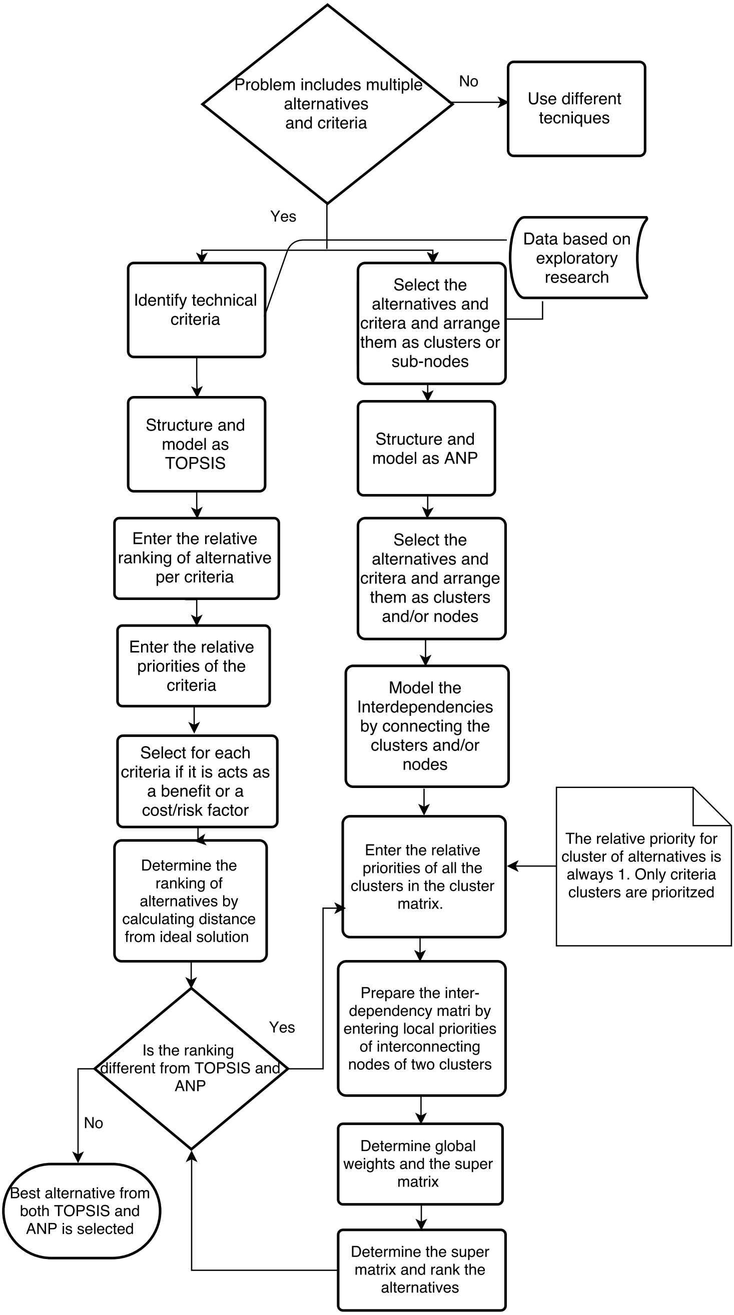


Figure 4.5: Flow Diagram for TraAdeCIS

4.2 Implementation Architecture for TrAdeCIS

The architecture of the system follows the community standards with full web stack of Django and Django REST frameworks and exposes endpoints for all functionalities of the system. As the implementation has Single Page Application (SPA) architecture, the data flow is minimized (only the necessary data is loaded, no markup). The server consists of the decision making logic and the database where the decisions made in the past and its corresponding data are stored. The client initiates the request through the Graphical User Interface (GUI) by entering the input in form of relevant factors, alternatives, and their corresponding relative rankings. The server responds by ranking the alternatives based on MADA of TOPSIS (for technical factors) and ANP (for economical and organizational factors).

4.2.1 Logical Model of TrAdeCIS

The prototype of TrAdeCIS follows the design as mentioned is previous section and has three major steps for selecting the most optimal alternative (cf. Figure 4.5). The alternatives are ranked from (1) technical perspective, (2) economical and organizational perspective, and (3) then trade-offs are established to select the best (most optimal) alternative.

- **Ranking of Alternatives from Technical Perspective** TrAdeCIS uses TOPSIS for ranking the alternatives with respect to technical factors. TOPSIS does pair wise comparisons across all criteria, and facilitates compensations for high negative criterion with an equally strong positive criterion. Technical requirements can be interdependent, and can also be categorized as a risk or a benefit towards selecting an alternative. Also, TOPSIS is scalable to high number of criteria and alternatives (which was evaluated in testing phase of development), as is required for evaluating alternatives from technical perspective. TOPSIS is implemented as shown in Listing 4.1. TOPSIS implementation for ranking alternatives expects following three inputs:

- matrix, a NxM matrix of the values (performance of alternatives with respect to each criteria) with N criteria as columns and M alternatives as rows.
- weights, N priority values/ranking in order to prioritize the criteria or factors.
- has_positiv_effect, N true or false values, which say if the criteria has a positive impact (benefit) on the result or a negative impact (risk).

As shown in code snippet 1, based on the input provided, the first step is to normalize the matrix as well as the priorities of factors in order to gain uniform values, which can then be compared. From the normalized and weighted matrix the minimum and maximum values are taken for each criteria for later use. After that the best possible solution is computed by taking the maximum value if the criteria has a positive effect on the result or the minimum value if it has a negative impact on the result. The worst possible solution is constructed by taking the minimum value, if the impact is positive and the maximum value, if the impact is negative. The next step is to compute the distance of the matrix to the ideal as well as the anti-ideal solution. This is done by computing the Euclidean distance. Finally the relative closeness is computed. Ranking of alternatives is based on the relative closeness of alternatives to the ideal solution. Higher the value, higher is the ranking of the alternative. The complexity[1] of the TOPSIS algorithm, with respect to implementation shown above is $O(N * M)$ where M is the number of alternatives and N the number of criteria.

[1]Complexity: $N * (M + (M - 1) + M^{1/2}) + 2 * M * N + 2 * N + 2 * (N * (M + (M - 1) + M^{1/2}) + 2 * N = 8 * M * N + N + 3 * M^{1/2} = O(M * N)$

Listing 4.1: Python Implementation Excerpt for TOPSIS

```
def topsis(matrix, weights, has_positiv_effect,
    normalization=vector_normalization):

    # normalize and apply weights
    weighted_matrix = normalization(weights) *
        normalization(matrix)²

    # extract min and max values for each column
    mins = numpy.min(weighted_matrix, axis=0)³
    maxs = numpy.max(weighted_matrix, axis=0)³

    # create ideal and anti ideal arrays
    ideal = numpy.where(has_positiv_effect, maxs, mins
        )⁴
    anti_ideal = numpy.where(has_positiv_effect, mins,
         maxs)⁴

    # calculate distances to the ideal and anti ideal
        arrays
    distance_ideal = norm(weighted_matrix - ideal,
        axis=1)²
    distance_anti_ideal = norm(weighted_matrix -
        anti_ideal, axis=1)²

    # compute relative closeness
    relative_closeness = distance_anti_ideal / (
        distance_ideal + distance_anti_ideal)⁵
    return relative_closeness
```

- **Ranking of Alternatives from Business Perspective** The next step of TrAdeCIS is the ranking of alternatives from economical and organizational factors (cf. Figure 4.5). ANP is generalization of the AHP, and is a method where dependencies can be modeled between any of the elements. These alternatives and criteria are modeled as clusters (comprising of 1 or more nodes), and are connected as a network. Each connection symbolizes the interdependency between the 2 connected nodes or clusters. While it results in modeling of more

[2] Number of executions: $N * (M + (M-1) + M^{1/2})$, for N columns the M values are squared, summed and then the square root of the sum is taken (vector normalization)

[3] Number of executions: $M * N$, for N columns check the values

[4] Number of executions: N, create arrays with N values

[5] Number of executions: $2 * N$, N additions and divisions

accurate models, but also increase the complexity of the input needed. Also, ANP allows for modeling the interdependence among the criteria and the alternatives, that means the performance of alternatives in criteria also effect decision made. For example, if all the alternatives are highly cost-effective, than the final weight for the criteria of cost can be lowered while making the final decision with ANP. In ANP the super matrix has to be constructed first. As shown in code snippet 4.2, we get the values of the super matrix, which where previously computed by the eigenvectors of all the possible pairwise comparison matrices. A pairwise comparison matrix, is a matrix where criteria or alternatives are compared with respect to another element (cf. Section 4.2.3). This comparison of criteria or alternatives is dependent on the set interrelations.

Listing 4.2: Javascript Implementation Excerpt for Generation of the Super Matrix in ANP

```
supermatrix: function (clusterNodes) {
    var children = graph.findChildren(
        clusterNodes);
    var matrix = utils.matrix(children.length,
         0);

    children.each(function (column, sourceNode
        ) {
      children.each(function (row, targetNode)
           {
        matrix[row][column] = graph.getValue(
            sourceNode, targetNode) || 0;
      });
    });

    return matrix
  }
```

In order to compute the result of ANP the expected input is the super matrix as well as the number of alternatives. An additional constraint is that alternatives are always the last n elements of the super matrix, where n is the number of alternatives. The result is then constructed by computing the limit matrix, and transforming it into an array, which gives the ranking of each alternative. In order to compute the limit matrix, the super matrix has to be raised to high odd powers until it converges. It can be shown that the limit exists if the matrix is column stochastic [101].

The computation of limit matrix (as shown in code snippet 4.3) is an iterative process where the matrix is raised by the power of 3 and then again normalized in order to keep the matrix column stochastic. Then the result is checked if it is equal up to the 8th decimal precision with the previous result. If so, the process is ended. Usually this takes around 3 iterations to find a result. The number of iterations depends on the limit of the super matrix (the power at which the matrix converges), and therefore on the values in the super matrix, which consist of the global cluster comparison, the criteria comparison of the cluster, and the criteria value.

Listing 4.3: Python Implementation Excerpt for Generation of Limit Matrix in ANP

```
def limit_matrix(matrix):
    result = matrix
    previous_matrix = result

    while True:
        result = linear_normalization(numpy.linalg.
            matrix_power(result, 3))[6]

        if numpy.isnan(numpy.sum(result))[7]:
            raise ArithmeticError('received not a 
                number')

        if numpy.allclose(previous_matrix, result)[8]:
            break

        previous_matrix = result

    return result
```

[6]Number of executions: $2*N^3$, two matrix multiplications are done, matrix multiplication has a complexity of $O(N^3)$

[7]Number of executions: $M * N$, all the values are summed up

[8]Number of executions: $M * N$, all the values are compared

The reason for raising the super matrix by the power of 3 is that odd numbers have the advantage of preserving the structure of the matrix (in matrix multiplication, depending on where a zero is the other values might switch places with the zeros). When the limit is found, the values for the whole row are the same. The advantage, however, is that if is raised by an odd number the first column will certainly have non-zero values. These values denote the ranking of the alternatives. Another advantage is that by consecutively raising the matrix by 3 in the end the matrix will be raised by *3x*, where x is the number of iterations. Higher the value of x lesser iterations will be needed. The value of 3 is chosen so as to maintain a balance between the rising complexity of the computation with higher values of x, and the number of iterations needed to compute the limit matrix.

The complexity[9] of the algorithm is $O(N^3)$, N the dimension of $N * N$ super matrix.

- **Establishing Trade-offs** Once the ranking of alternatives is obtained from TOPSIS (from technical perspective) and ANP (from business-economical and organizational-perspective), a trade-off strategy is required if the ranking is different. TrAdeCIS therefore, as shown in Figure 4.5, compares the ranking and gives an option to the decision maker to select the best technical solution at trade-offs of business value. Trade-offs are achieved by altering the priorities of the criteria, based on which the alternatives are evaluated. The possibility of calculating the interdependence of attribute and ability to forecast benefits, costs, and risks qualify ANP for establishing a trade-off strategy for cloud adoption. There are essentially three possible dimensions at which priorities can be adjusted in ANP:

[9] Complexity: $2 * N^3 + M * N + M * N = O(N^3)$

Algorithm 1 Algorithm for Establishing Trade-offs

▷ % S_x denotes the super matrix x
▷ %: L_x denotes the limit matrix of super matrix x
▷ %: *Row* is the set of elements in a row of a super matrix or limit matrix
▷ %: *Node* denotes to a criteria or alternative
▷ %: *inc* denotes the value by which values of super matrix has to be increased
▷ %: *dec* denotes the value by which values of super matrix has to be decreased
▷ %: *current_value* denotes an element of original super matrix
▷ %: *relative_change* $= 0.5 *$ (minimum element of the original normalized super matrix)

Compute the limit matrix L_c from the current super matrix S_c

for each row in the super matrix **do**
  $inc = relative\_change/(1 - (current\_value + relative\_change))$
  $dec = relative\_change/(1 + (current\_value - relative\_change))$
  Construct super matrix S_{row+} by increasing each element in *Row* by *inc*
  Construct super matrix S_{row-} by decreasing each element in *Row* by *dec*
end for

for each constructed super matrix $\in \{S_{row+}, S_{row-}\}$ **do**
  Compute the limit matrix L_{row+}
  Compute the limit matrix L_{row-}
end for

for each computed limit matrix $\in \{L_{row+}, L_{row-}\}$ **do**
  Compute the differences to the original limit matrix L_c, $L_{row+} - L_c$ and $L_{row-} - L_c$
end for
Sort the the differences of the limit matrix in the previous step to obtain a list of the nodes which have the highest impact

for each positive difference of the limit matrix **do**
  Repeat the process but only specific to one element at a time
end for

(1) At the global cluster level, prioritizing an entire cluster compared to others. The alternatives cluster can also be compared as an exception to other clusters if needed. (2) At the cluster level, comparing the importance of criteria in a cluster.

(3) At the criteria level, changing the values of the comparison matrix. Trade-offs are suggested by TrAdeCIS based on the Algorithm 1 when the ranking obtained with TOPSIS and ANP do not match. This algorithm leads to the identification of the node (or criteria) that is interrelated to the alternative (say A1): when changed in terms of its associated priority, will make that alternative (A1) the highest ranked alternative as per ANP too. The algorithm is based on the concept that a column of the super matrix shows the influence that a node has on other criteria and alternatives (outgoing influence). Therefore, by increasing and decreasing the row values in a super matrix the influence of a node to the final rankings as per ANP can be evaluated. Hence, the approach developed and followed here for calculating trade-offs is outlined in Algorithm 1. The increase (*inc*) and decrease (*dec*) for each element of original super matrix as shown in Algorithm 1 is calculated using on the current normalized value and half of the minimum element of the original super matrix (*relative_change*). Choosing *relative_change* to be less than the minimum element of the super matrix removes the possibility of division by zero error in *inc*. Also, *dec* will never be zero or negative, because the *relative_change* is smaller than the lowest value in the super matrix. Consequently, by calculating the limit matrices (L_{row^+}, $L_{row^-}\}$), and their differences to the original limit matrices ($L_{row^+} - L_c$ and $L_{row^-} - L_c$), the influence of the row on the final ranking of ANP is calculated. The final step for establishing trade-offs is to repeat this process specific to each element of the row that comprised of positive difference of limit matrices in the previous step. The element with the highest positive difference has the maximum influence on the ranking of the alternative, that has to be ranked the highest as per ANP. The final ranking is calculated automatically by TrAdeCIS based on the selected trade-offs from the list

of recommendations provided by system, which leads to the variation of some of its factors' values.

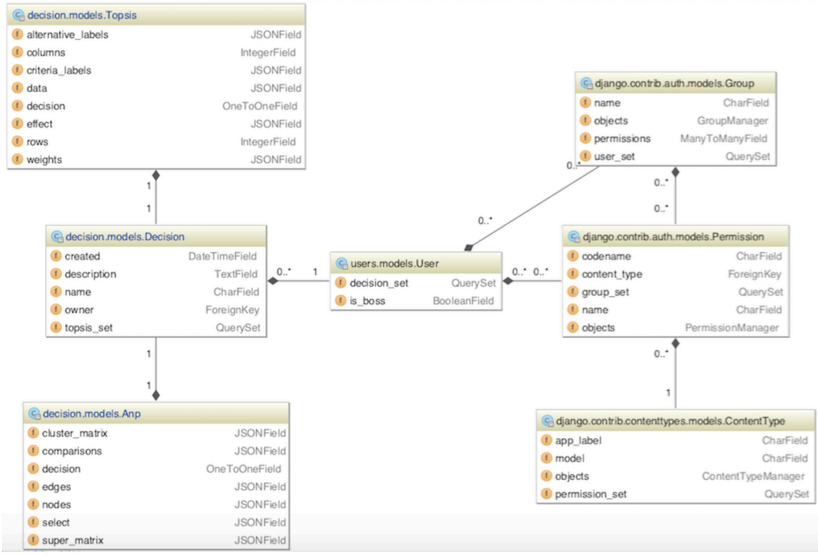
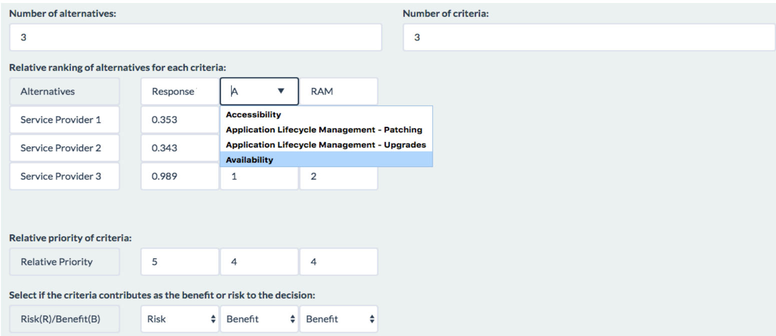


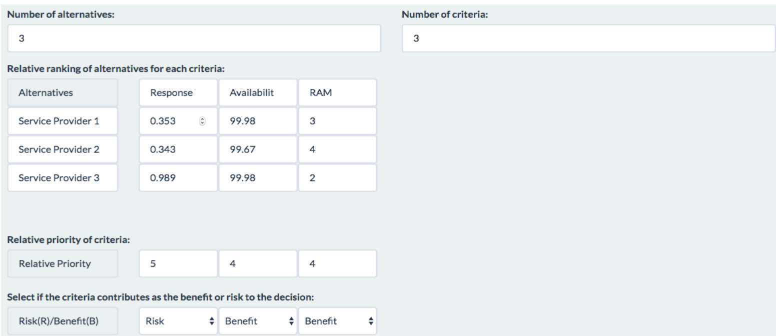
Figure 4.6: Database Models of TrAdeCIS

4.2.2 Database

In Django coherent logic is bundled in a so-called "app". TrAdeCIS is built with two apps: (1) "mcda" for storing, computing and visualizing TOPSIS and ANP, and (2) "account" to manage the different access levels which TrAdeCIS provides. The app "account" handles the permissions within TrAdeCIS. Different level of access levels – user, organizational leader, and admin – define the rights of the user while using the system. For example, an organizational leader is able to view and edit data specific to his organization. A user, however, is able to view and edit only his own data. The app "mcda" consists of three database models namely Decision, TOPSIS and ANP (cf. Figure 4.6). These models determine the logical structure of the database of TrAdeCIS and fundamentally determine the manner in which data can be stored, organized, and manipulated. Decision model denotes decision that consists of a name and optional description for the decision to be made. The input and output data for TOPSIS and ANP are stored in their respective models. The access as well as the modification of the data is exposed via REST endpoints by utilizing the 'Django REST Framework", which simplifies the creation of REST APIs with Django.



(a) Factors Selection for TOPSIS



(b) TOPSIS Model

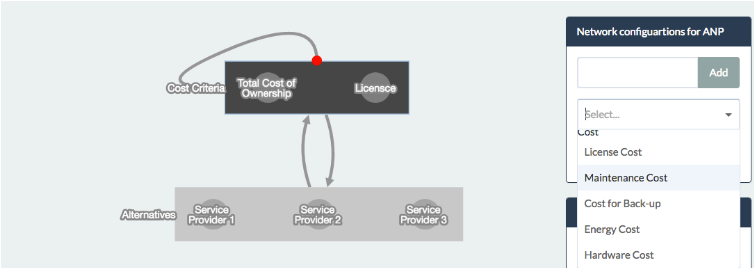
Figure 4.7: Modeling Technical Requirements with TOPSIS

4.2.3 User Interface

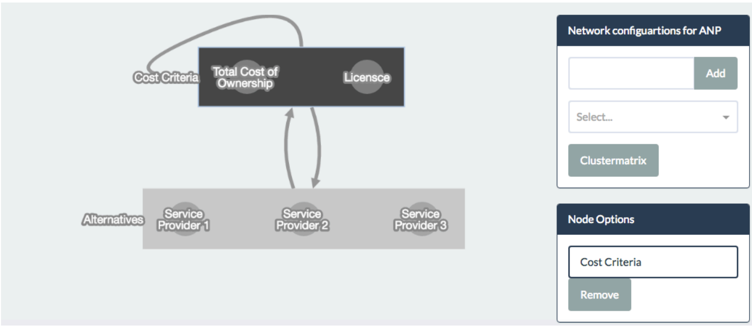
The methodology of TrAdeCIS has been fully implemented as a web-based platform. This is done to facilitate (a) the validation of concepts in practical environment, (b) allow demonstrations, (c) facilitate the comparative testing of TrAdeCIS in other domains than that of cloud computing, and (d) enable the release of the platform to relevant industry, academia and research community. The SPA user interface is built with several new technologies as introduced here: (1) "React.js" is an open-source JavaScript library developed and maintained by Facebook that provides a view for data rendered as HTML. React creates an in-memory data structure cache, computes the resulting differences, and then updates the browser's displayed Document Object Model (DOM)efficiently. The key feature is that a webpage is built with reusable components, which are defined by programmer. (2) "Webpack" is a module bundler that allows to build browser javascript which can be modularized. Webpack is also valuable for minification of code, import of other files (*e.g.,* css), or removing unused code. (3) "Redux", is a state management library thats makes the state immutable at all the time and therefore leads to a clearer as well as better testable state. Additional new technologies and concepts like "Css Modules", "PostCss", "ES6", "JSX" along with libraries of "React-Router", "Cytoscape" and "Chartjs" were also used to develop the front-end for TrAdeCIS. The implementation is based on the flow shown in Figure 4.5, and the graphical user interface (GUI) is presented with screenshots and clarification on how it is operated by the user, relating its functionality to its components.

- **Ranking of Alternatives per Technical Requirements** As shown in Figure 4.8a the decision makers are expected to select and weight the technical criteria. In the example shown in Figure 4.7b response time is prioritized as the highest criteria. Finally a decision maker sets if a criterion act as risk or a benefit towards the selection of the alternative. In the example shown in Figure 4.7 response time is valued as a risk (a high response time is a disadvantage for the adoption of any alternative). Also, performance values of every alternative with respect to criteria of service response time, availability, and RAM are entered. As per these inputs Service Provider 2 is ranked the highest as per the technical requirements.

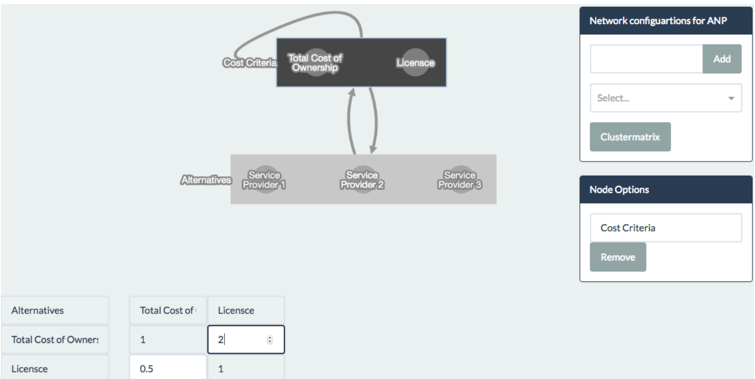
- **Ranking of Alternatives per Business Requirements** The next step is to rank the same alternatives with respect to economical, and organizational factors (cf. Figure 4.8a). As discussed before, modeling of decision with ANP is done based on interconnected clusters that comprise of 1 or more nodes. In the example shown in Figure 4.8b the alternatives are ranked for the criteria of TCO and License Cost. The cluster of Cost also has a self-loop (cf. Figure 4.8c) that enables decision maker to prioritize the sub-criteria within a cluster. In this example, TCO is twice as important as License Cost. The next step is to perform pair wise comparisons of all the clusters with every cluster to which they are connected with respect to the selected criterion. Upon selection of a sub-criterion all the connections which are possible in the model as well as the pairwise comparison matrix are shown. For example, in Figure 4.9a and 4.9b, comparison of service providers is shown with respect to the criteria of TCO and license cost, respectively. Also, as the clusters of alternative and criteria are connected bidirectionally, Figure 4.10a, 4.10b, and 4.10c compare the performance of each service provider separately with respect to both criteria of License Cost and Total Cost of Ownership. For example, service provider 2 is performing 3 times better in TCO as compared to License Cost. Based on this modeling and prioritization of business requirements, ANP ranks Service Provider 2 as the highest.



(a) Factors Selection for ANP

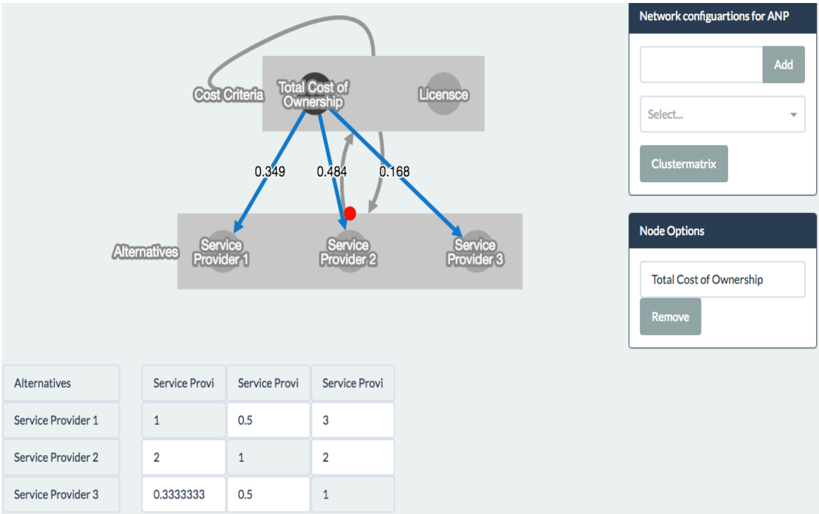


(b) ANP Model



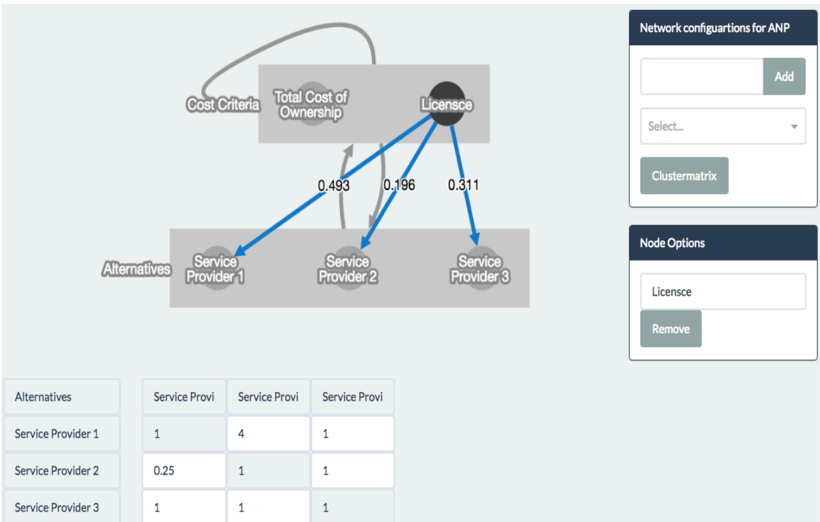
(c) Prioritizing Factors for ANP

Figure 4.8: Modeling Business Requirements with ANP



Alternatives	Service Provi	Service Provi	Service Provi
Service Provider 1	1	0.5	3
Service Provider 2	2	1	2
Service Provider 3	0.3333333	0.5	1

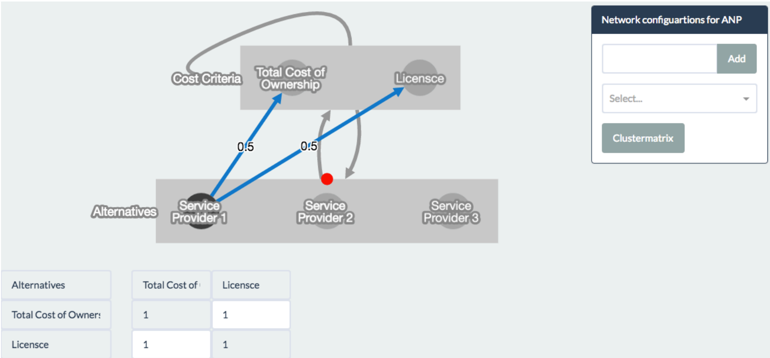
(a) Comparison Matrix for Total Cost of Ownership



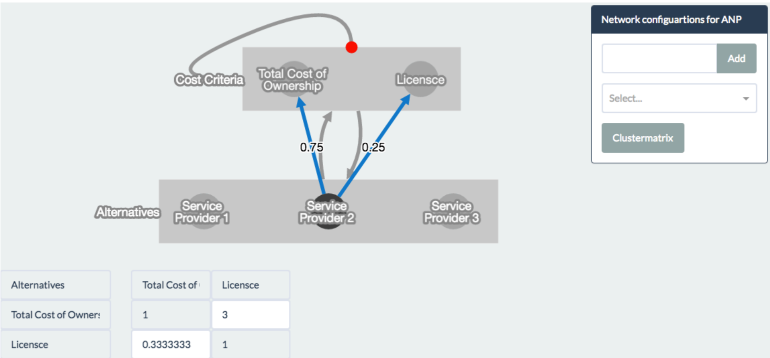
Alternatives	Service Provi	Service Provi	Service Provi
Service Provider 1	1	4	1
Service Provider 2	0.25	1	1
Service Provider 3	1	1	1

(b) Comparison Matrix for License Cost

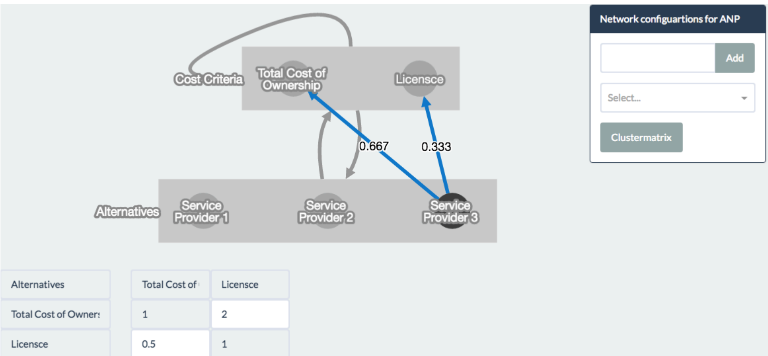
Figure 4.9: ANP Model with Comparison Matrices for Criteria



(a) Comparison Matrix for Service Provider 1



(b) Comparison Matrix for Service Provider 2



(c) Comparison Matrix for Service Provider 3

Figure 4.10: ANP Model with Comparison Matrices for Alternatives

- **Establishing Trade-offs** As both TOPSIS and ANP is ranking Service Provider 2 as the highest, establishing trade-offs by altering the priorities of ANP is not necessary. In the cases when trade-offs are required, TrAdeCIS supports it by allowing the user to change the priorities of the factors in the comparison matrices. This implies that a user can change one of the following priorities to establish trade-offs:
  - **Cluster Matrix Priorities:** At the global cluster level, all the clusters of criteria can be relatively prioritized. The changes made in the relative priorities by pair wise comparing all clusters, represents the first possible trade-off.
  - **Criteria Priorities:** At the cluster and node level, all the criteria and sub-criteria can be prioritized by pair wise comparisons. Altering the importance of any criterion or sub-criterion in a cluster represents the second possible trade-off within TrAdeCIS.

4.3 Impact Analysis

Once the best alternative is identified using TrAdeCIS it is crucial to identify the impact of adopting this solution on an organization. The impact analysis establishes the relationship of "cause and effect" of any change adoption of cloud-based services will bring in an organization. The new methodology developed in this thesis – termed Impact Analysis Methodology for Cloud-based Services (IAMClS) – is driven by the notion that it is difficult for large IT architectures to estimate the impact at a high level [42], [44]. If the impact is accurately predicted it will result in minimization of operating cost, identification of uncertainties in terms of relevant technical factors (such as security, privacy, reliability), and counter-measures needed in advance to reduce the adverse effect, if any. These counter-measures can be in terms of any structural changes in organization such as number of personnel required and their qualifications. Since the complexity for cloud-based architectures is too high, it is modularized into components, so that each can be evaluated individually, for enabling the estimation of the overall impact of the solution to be adopted. IAMClS consists of following steps:

1. **Identification of Components of Cloud-based Service:** This step identifies components of the cloud-based service by decomposing the entire service into independent units, *e.g.,* servers, operating system, database. IAMClS supports the quantification of impact by efficiently aggregating the individual impact of the decomposed components back to the overall impact distribution. For example, when a certain infrastructure requirement is fulfilled by a cloud-based solution, it can have components in terms of virtual machines, servers, and storage space.

2. **Identification and Modeling of Relevant Factors:** For this step the input of TrAdeCIS in terms of relevant factors (technical, economical, and organizational), their values, priorities, and interrelations (as modeled in ANP) are re-used. These factors are used to evaluate the performance of cloud-based service.

3. **Calculation of Impact:** Finally, each of these expected values of the factors are associated with a probability of failure and its consequent loss. Both of these values are associated with failure of each component with respect to an individual factor. These values are based on the experience of the decision maker and the market analysis of the service provider.

   The final impact (I) for m components, each having n factors to be evaluated, is denoted by I. l_{ij} define the loss and p_{ij} denotes the probability of expected value of factor i of component j not being fulfilled. The interrelations of these factors are translated as conditional values of l_{ij} and p_{ij} (illustrated in Use Case below). Also, w_{ij} symbolizes the priority of the factor i of component j.

$$I = \sum_{1 \leq i \leq n} \sum_{1 \leq j \leq m} w_{ij} \cdot l_{ij} \cdot p_{ij} \tag{4.2}$$

The range of probability is as follows: $0 \leq p_{ij} \leq 1$. l_{ij} can have a value of high, medium, low level of losses. These three levels of losses can be replaced with any three positive integers in the equation, while calculating the quantitative impact, where high loss is replaced by the highest integer and a low level takes the lowest integer. I_{sev} indicates the relative impact to the worst case value and is calculated as follows:

$$I_{sev} = I \div \left(\sum_{1 \leq i \leq n} \sum_{1 \leq j \leq m} w_{ij} \cdot (l_{ij})_{max} \cdot (p_{ij})_{max} \right) \tag{4.3}$$

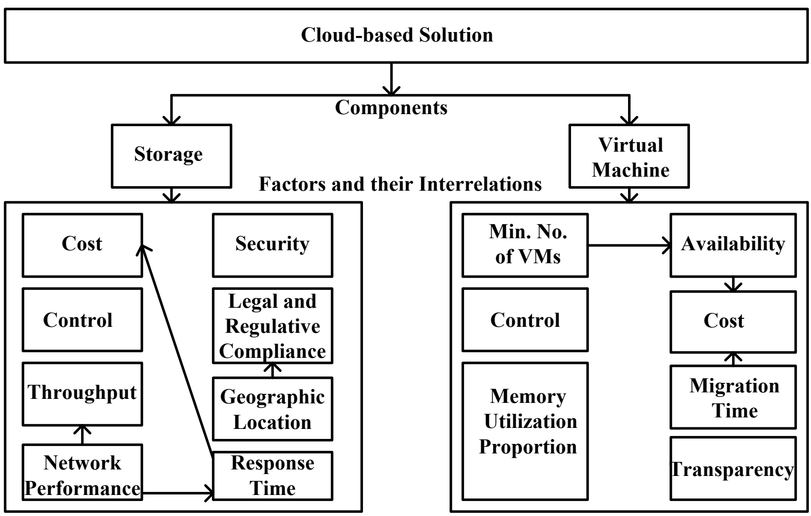


Figure 4.11: Identified Components of Cloud-based Service

4.3.1 Illustration of IAMCIS

In order to validate the applicability of this methodology developed above, organizations that participated in surveys (as shown in Chapter 3) were asked to evaluate current requirement of the organization for which cloud-based services are considered as a potential solution. The use case illustrated here is that of an organization, which provides networking solutions and plans to adopt cloud-based services in order to fulfill its infrastructure requirements. Following step-wise results were obtained when IAMClS was applied for this use case:

1. **Identification of Components of Cloud-based Service:** Identified components were storage space and virtual machines. As shown in Figure 4.11, for each of these components a list of factors was determined by the organization, which was used to evaluate and measure the performance of these components.

2. **Interrelations and Priorities between Factors:** In the next step, values of probability of failure per factor and its consequent associated loss are identified, as shown in Table 4.1. These values were obtained in personal discussions with the organization during the survey. Loss is calculated by estimating the cost of failure, *i.e.,* when an expected value of a factor is not achieved. Cost is mapped to three levels of loss (High, Medium, or Low). Probability of failure is identified by the decision maker based on the evaluation of the performance of a cloud-service for a factor in the past. For interdependent factors the values of probability of failure and its associated loss are calculated cumulatively as shown in Table 4.1. Based on those requirements of the organization following interrelations Figure 4.11 as shown in were identified:

   Storage Space: Throughput is the number of transmitted data per time unit. This depends on the network performance.

Also response time depends on the network performance. If the response time is too high, it will be more costly to the organization. In addition, the location where data is stored, and the level of security provided by the cloud-service provider are important factors to ensure legal and regulative compliance.

Table 4.1: Probability of Failure For Factors and Its Associated Loss

Compo-nent	**Factor(s), Priority**	**Probability of Failure**	**Loss**
Storage Space	Throughput due to Network Performance, 3	0.2	Medium
Storage Space	Security, 5	0.4	Medium
Storage Space	Response Time due to Network Performance, 4	0.3	High
Storage Space	Additional Cost due to Response Time, 2	0.2	High
Storage Space	Legal and Regulative Compliance and Geographical Location, 4	0.5	High
Storage Space	Storage Cost, 4	0.2	High
Virtual Machine	Minimum Number of VMs and Availability, 7	0.2	High
Virtual Machine	Cost for VMs, 4	0.2	Medium
Virtual Machine	Migration Time, 6	0.3	High
Virtual Machine	Additional Cost due to Migration time, 3	0.5	High
Virtual Machine	Transparency, 4	0.5	Medium
Virtual Machine	Control for VM	0.4	High
Virtual Machine	Memory Utilization Proportion	0.4	High

Virtual Machines: Number of VMs needed depends on the workload and guaranteed level of availability of cloud-based service. This in turn influences the cost of an organization.

Also, the time taken to migrate data and applications to cloud-based infrastructure (leading to down-time of the application) influences the cost, that an organization has to bear.

Table 4.2: Factors and Their Expected Values

List of Factors	Expected Value
Throughput	Sustained Read throughput for vol. size of 1 GB is 0.15 MB/s Sustained Write throughput for vol. size of 1 GB is 0.30 MB/s
Security	Encryption, authentication
Network Performance	Same region approximately 800 Mbit/s. For large files, if network error occurs, upload should start where it stopped. Bandwidth should be saved
Response Time	6-8 ms (even at peak times)
Control for Storage	Internal staff should have access to data as per the need
Legal and Regulative Compliance	Data residency: storing data in the same geographical region as that of organization. Certificates like ISO 27001, SSAE- 16, SOC 1 needed
Geographic Location	Data is to be stored within the same region
Cost for Storage	0.02 GB/month
Minimum number of VMs	2 instances in the same availability set
Availability	99.5%
Migration Time	For around 1000 concurrent users downtime should not be greater than 4 seconds for one migration.
Cost for VMs	Approx 550 US$ per month, with 8 cores, 15 GB RAM, disk size 600 GB
Transparency	Load balancing to handle additional load, to be integrated via a management API
Control for VMs	Internal staff should have access to data as needed
Memory Utilization Proportion (mem)	$40\% \leq mem \leq 80\%$

3. **Evaluating Expected Value for the Identified Factors:** As shown in Table 4.2 for each of those factors an expected value was identified. These values cumulatively mark the expected performance level of components.

4. **Calculating Impact:** Based on the value of priority, probability of failure, and its associated loss, for each factor, the impact of cloud-based service on an organization is quantified. Applying Equation 4.2 for estimating the potential impact of adopting this cloud-based solution leads to the value of I equaling 40.9, which is obtained as follows:

   $I = (3 \cdot 0,2 \cdot 2) + (5 \cdot 0,4 \cdot 2) + (4 \cdot 0,3 \cdot 3) + (2 \cdot 0,2 \cdot 1) + (4 \cdot 0,5 \cdot .3) + (4 \cdot 0,2 \cdot 3) + (7 \cdot 0,2 \cdot 3) + (4 \cdot 0,2 \cdot 2) + (6 \cdot 0,3 \cdot 3) + (3 \cdot 0,5 \cdot 1) + (4 \cdot 0,5 \cdot 1) + (5 \cdot 0,5 \cdot 2) + (5 \cdot 0,4 \cdot 3)$

   The higher the value of I, the more adverse is the impact of a cloud-based service on the organization. Here, the value of I_{sev} is approximately at 25%, as calculated with Equation 4.3. Therefore, the considered cloud-based service does not have severe negative impact, even if all of these factors, are not fulfilled (worst case scenario). The result of applying IAMClS is the indication of how severe the impact of decision of adopting a particular cloud-based service will be on the organization, if any of the expected value is not fulfilled for the relevant factors. This also helps an organization to prepare for possible countermeasures, in order to handle any adverse impact (when an expected value for a factor is not achieved) due to the adoption of new cloud-based solution.

4.4 Chapter Summary

With the aim to provide a quantified methodology for decision making of adopting cloud-based services in an organization, this chapter developed and implemented Trade-offs based methodology for Cloud-based Services as a web-based system. TrAdeCIS consists of three major components of identification and modeling of requirements, relative ranking of alternatives for all requirements, and establishing trade-offs. Quantifying the relative ranking of alternatives for all the qualitative requirements was achieved on the basis GRL graphs. These graphs modeled and divided requirements as multiple components of goals and soft goals. Higher the completion of these components by an alternative for a qualitative requirement or factor, higher will be its ranking. Final ranking of all the alternatives was quantitatively computed using multi-attribute decision algorithms of TOPSIS and ANP from technical and business perspective respectively. The system of TrAdeCIS facilitates and automates the computation of trade-offs, if the ranking of alternatives with respect to technical and business factors is not same. The decision maker can select one of recommended trade-offs, which leads to the variation of some of the priority values of business factors. Once the best alternative is identified using TrAdeCIS, IAMCIS is developed to predict the impact this alternative will have on organization in case of failure. This leads to identify and list the possible negative decision, and making an estimate of the size of the impact and the consequences of the decision.

5

Evaluation

To evaluate the validity and applicability of the methodology developed and implemented in this thesis, this chapter evaluates (1) different use cases that model varied interrelations of the factors, and evaluate different alternatives using the GUI developed for TrAdeCIS, (2) scalability and performance testing of algorithms, (3) generalization of TrAdeCIS to make decision of adopting a new technology besides that of Cloud Computing, and (4) complexity and feasibility of including temporal factor in TrAdeCIS. The data for the use cases was collected as part of survey done with organizations (cf. Chapter 3) who used web-based platform developed for TrAdeCIS to make decisions of selecting the best alternative for their IT requirements. In order to avoid scenario of insufficient data while evaluating cloud-based services, platforms of CloudHarmony Inc [22] and PaaS Profiles [95] were also used. These platforms were specifically used to obtain measured and monitored performance values of different CSPs for technical and economical factors.

5.1 Results Based on Prototype of TrAdeCIS

Two primary objectives drove the collection of these use cases and the subsequent evaluation of TrAdeCIS. First one was to determine the feasibility of modeling decisions that includes varied requirements that organizations would have to accomplish with TrAdeCIS. Second was to practically evaluate the methodology developed with a selected set of organizations surveyed within this thesis to identify relevant factors.

Table 5.1: Decision of Adopting IaaS - Input for TOPSIS

Alternatives	Availability (%)	Scale Up	Operating Systems
Amazon EC2	99.95	0	9
GoGrid	99.95	1	4
NephoScale	99.95	1	4
OpSource	99.95	1	4
Rackspace	99.95	1	8

5.1.1 Decision of Adopting IaaS (Use Case 1)

Use Case 1 (UC1) is an example of adopting IaaS with the alternatives and criteria under consideration as shown in Table 5.1. Organization *O1* (cf. Chapter 3), an ICT provider, needed to evaluate 5 CSPs that *O1* had used in past to fulfill its other IaaS requirements. This evaluation is done based on three technical parameters (*availability*, *scale up*, and *operating systems*) that are driven from the current requirements of *O1* for adopting IaaS. As all the criteria equally contribute to the evaluation of alternatives, their relative ranking is same. In addition, all the criteria have a positive influence (benefit) on the result. This means higher the value of an alternative with respect to these factors, higher will be the rank of that alternative. This is true for all the factors of availability (higher availability is desired), scale up (alternative should be able to scale up as per the demand), and operating systems (higher number of OS should be supported). The value of *availability* is the percentage value respective alternative provided to current cloud service customer as measured by [22]. Factor of *scale up* has a boolean value (true or false) denoting if scaling up of the resource is possible or not. With *scaling up*, one can ensure that the number of instances that are in use can scales up seamlessly during demand spikes to maintain performance. *Operating systems* denote the number of different OS that are supported (usually VMs) by the resource. Ranking these alternatives with TOPSIS results in Rackspace being the best alternative.

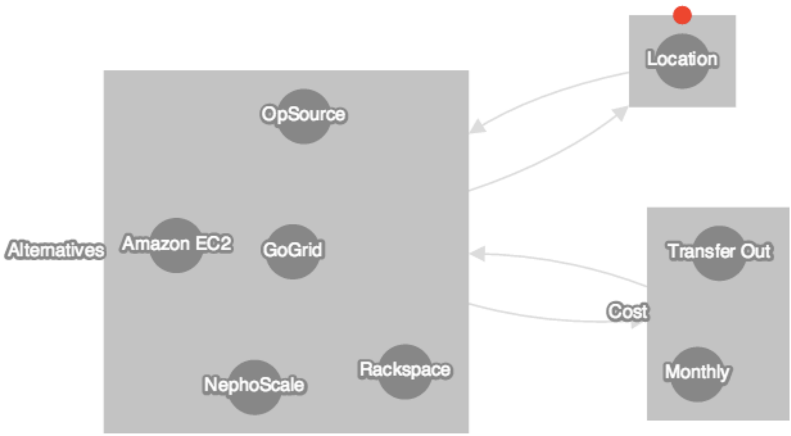


Figure 5.1: Decision of Adopting IaaS - ANP Model

In order to compare these alternatives from the business perspective (including economical and organizational factors) the model shown in Figure 5.1 is constructed. This model consists of clusters of alternatives and factors. Each cluster (represented by a box) consists of one or more nodes (represented by a circle). These nodes represent various alternatives for the cluster of alternative, and sub factors for every cluster corresponding to a factor. The cluster of *Location* denotes the number of places where a server exists. The cluster for the factor of *cost* is divided into *monthly cost* and *transfer cost. Monthly cost* denotes the total costs associated with alternatives for each month. *Transfer out* is the cost which arise per GB of outbound Internet traffic. Here the compared criteria have no interrelations between each other as the factor of location and costs do not influence each other. In other words, change in value of one factor does not change the value of other. Therefore, the pairwise comparison matrices for *Location* (cf. Table 5.2), *monthly cost* (cf. Table 5.3), and *transfer out* (cf. Table 5.4) are computed with the values of each of the alternatives for these factors. For example in Table 5.2 relative value of Amazon EC2 with GoGrid signifies that Amzon EC2 has 7 places where a server exists, while GoGrid has servers at 2 places.

Table 5.2: Decision of Adopting IaaS - Comparison Matrix for Location

Location	Amazon EC2	GoGrid	NephoScale	OpSource	Rackspace
Amazon EC2	1	7/2	7	7/4	7/9
GoGrid	2/7	1	2	1/2	2/9
NephoScale	1/7	1/2	1	1/4	1/9
OpSource	4/7	2	4	1	4/9
Rackspace	9/7	9/2	9	9/4	1

Table 5.3: Decision of Adopting IaaS - Comparison Matrix for Monthly Cost

Monthly Cost	Amazon EC2	GoGrid	NephoScale	OpSource	Rackspace
Amazon EC2	1	273.6/80.81	146/80.81	87.6/80.81	51.1/80.81
GoGrid	80.81/273.6	1	146/273.6	87.6/273.6	51.1/273.6
NephoScale	80.81/146	273.6/146	1	87.6/146	51.1/146
OpSource	80.81/87.6	273.6/87.6	146/87.6	1	51.1/87.6
Rackspace	80.81/51.1	273.6/51.1	146/51.1	87.6/51.1	1

Table 5.4: Decision of Adopting IaaS - Comparison Matrix for Transfer Out

Transfer Out	Amazon EC2	GoGrid	NephoScale	OpSource	Rackspace
Amazon EC2	1	0.29/0.12	0.13/0.12	0.15/0.12	0.18/0.12
GoGrid	0.12/0.29	1	0.13/0.29	0.15/0.29	0.18/0.29
NephoScale	0.12/0.13	0.29/0.13	1	0.15/0.13	0.18/0.13
OpSource	0.12/0.15	0.29/0.15	0.13/0.15	1	0.18/0.15
Rackspace	0.12/0.18	0.29/0.18	0.13/0.18	0.15/0.18	1

Table 5.5 shows the resulting super matrix computed from the eigenvectors of the comparison matrices. Finally when the column of numbers is the same for every column, the limit matrix has been reached and the matrix multiplication process is halted resulting in Table 5.6. These values with respect to the alternatives of Amazon EC2, Go Grid, NephoScale, Op Source, and Rackspace are (0.2890, 0.085, 0.089, 0.186, 0.351).

Table 5.5: Decision of Adopting IaaS - Resulting Super Matrix

	Monthly Cost	Transfer--Out Cost	Location	Amazon EC2	GoGrid	Nepho Scale	OpSource	Rackspace
Monthly Cost	0	0	0	0.1	0.1	0.1	0.1	0.1
Transfer-Out Cost	0	0	0	0.1	0.1	0.1	0.1	0.1
Location	0	0	0	0.2	0.2	0.2	0.2	0.2
Amazon EC2	0.117	0.133	0.308	0	0	0	0	0
GoGrid	0.033	0.054	0.083	0	0	0	0	0
NephoScale	0.062	0.121	0.042	0	0	0	0	0
OpSource	0.104	0.104	0.175	0	0	0	0	0
Rackspace	0.183	0.088	0.392	0	0	0	0	0

Table 5.6: Decision of Adopting IaaS - Resulting Limit Matrix

	Monthly Cost	Transfer--Out Cost	Location	Amazon EC2	GoGrid	Nepho Scale	OpSource	Rackspace
Monthly Cost	0	0	0	0.25	0.25	0.25	0.25	0.25
Transfer-Out Cost	0	0	0	0.25	0.25	0.25	0.25	0.25
Location	0	0	0	0.5	0.5	0.5	0.5	0.5
Amazon EC2	0.289	0.289	0.289	0	0	0	0	0
GoGrid	0.085	0.085	0.085	0	0	0	0	0
NephoScale	0.089	0.089	0.089	0	0	0	0	0
OpSource	0.186	0.186	0.186	0	0	0	0	0
Rackspace	0.351	0.351	0.351	0	0	0	0	0

The higher the value in the limit matrix with respect to an alternative, the higher is the ranking of that alternative. This results in Rackspace being ranked the highest from business perspective. Since the result of both algorithms was Rackspace no trade-offs' calculation is necessary.

5.1.2 Decision of Adopting Virtual Machines (Use Case 2)

The input values for TOPSIS for Use Case 2 (UC2), as shown in Table 5.7, are obtained with respect to alternatives of Virtual Machines (VM) that are offered by 5 different providers. Each of the alternative features configurable memory *(RAM)*, CPU, and *SSD-based storage* options to better match cloud resources with the specific performance requirements of organization *O2* (cf. Chapter 3). *Virtual CPU (vCPU)* also known as a virtual processor, is a physical central processing unit (CPU) that is assigned to a VM. Therefore, here *vCPU* represents the number of vCPU allotted to VM. The showed criteria have equal priorities and are considered to have positive impact on the decision. Therefore, higher the values of an alternative for these factors, higher will be its final ranking. After applying TOPSIS for the evaluation of alternatives from technical perspective Microsoft Azure is ranked the highest.

Table 5.7: Decision of Adopting VM - Input for TOPSIS

Provider	VM Instance	vCPU	RAM (GB)	Storage (GB SSD)
CloudSigma	customized	1	2	50
DigitalOcean	standard2	2	2	40
Internap	B-1	1	4	20
Microsoft Azure	D1	1	3.5	50
Rackspace	General1-2	2	2	40

The alternatives as identified within TOPSIS are to be ranked next with respect to business criteria of *annual cost*, *migration cost*, and *migration time*. The interrelations between these criteria are modeled in ANP by the decision maker of organization

O2 using GUI developed for TrAdeCIS. The input for ANP is entered as pair wise comparison matrices of alternatives and criteria. These matrices are based on the interrelations (cf. Figure 5.2) that exists for every node in the network. The relative performances of alternatives per criteria are shown in comparison matrices (cf. Table 5.8 - Table 5.10). For example, Cloud Sigma is performing 4 times better than Internap in terms of *annual cost*. These values of comparison matrices are obtained based on the values measured by [22].

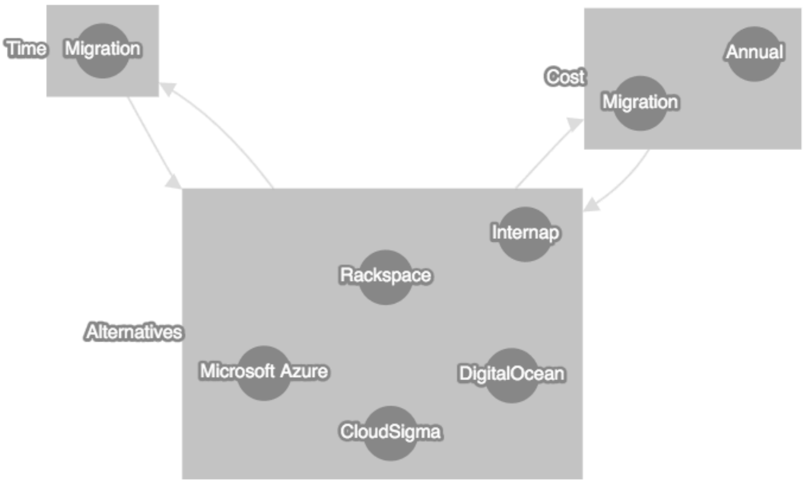


Figure 5.2: Decision of Adopting VM - ANP Model

In this use case the comparison matrices (cf. Table 5.11 - Table 5.15) are also constructed to specify the relative performance of one criteria over the another with respect to every alternative individually. For example, Cloud Sigma is performing twice better in terms of *annual cost* as compared to *migration cost*. In the next step super matrix is generated by TrAdeCIS based on the Eigen vectors of these comparison matrices (cf. Table 5.16). The values of limit matrix for the alternatives of CloudSigma, DigitalOcean, Internap, Microsoft Azure, and Rackspace are (0.297, 0.154, 0.125, 0.278, 0.146) as shown in Table 5.17. Therefore, the highest ranked alternative is Cloud Sigma, and Microsoft Azure is at the second rank.

Table 5.8: Decision of Adopting VM - Comparison Matrix for Annual Cost

Annual Cost	CloudSigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
CloudSigma	1	1.5	4	4	3.5
DigitalOcean	0.666	1	3	3	2.5
Internap	0.25	0.333	1	1	0.666
Microsoft Azure	0.25	0.333	1	1	0.666
Rackspace	0.286	0.4	1.5	1.5	1

Hence, for this use case the ranking obtained from TOPSIS and ANP is not the same, and consequently the system recommends performing trade-offs. This is done by altering the priorities of the criteria in ANP. The GUI responds by calculating and displaying the nodes for which the priorities are to be altered during trade-offs establishment. ANP is more sensitive to values of clusters that consist of only one node or factor. For example, the impact *migration time* has on the final ranking of the alternatives is higher than that of *migration cost* or *annual cost*. In this use case by altering the relative priority of Microsoft Azure in the comparison matrices of its interconnected node has the highest positive influence for ranking Microsoft Azure the highest as per ANP (cf. Table 5.18) as per Algorithm 1. In order to identify the interconnected node that has the highest impact on change in the ranking, element specific limit matrices are shown in Table 5.19 for the rows as that positive values in Table 5.18. As according to Algorithm 1, priority value of migration time relative to Microsoft Azure should be changed to achieve the desired ranking. Altering this priority implies that decision maker now considers the performance of Microsoft Azure and Cloud Sigma at the same level with respect to *migration time*. The process applied here is that of marginal influence, wherein infinitesimal rate of change of the alternative ranking is calculated by TrAdeCIS with respect to the factor of *migration time*.

Table 5.9: Decision of Adopting VMs - Comparison Matrix for Migration Cost

Migration	CloudSigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
CloudSigma	1	2	2	0.2	2
DigitalOcean	0.5	1	1	0.25	1
Internap	0.5	1	1	0.5	1
Microsoft Azure	5	4	2	1	3
Rackspace	0.5	1	1	0.333	1

Table 5.10: Decision of Adopting VMs - Comparison Matrix for Migration Time

Migration Time	CloudSigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
CloudSigma	1	2	2	2	1
DigitalOcean	0.5	1	1	0.5	1
Internap	0.5	1	1	0.5	1
Microsoft Azure	0.5	2	2	1	3
Rackspace	1	1	1	0.333	1

Table 5.11: Decision of Adopting VM - Comparison Matrix for CloudSigma

CloudSigma	Migration Cost	Annual Cost
Migration Cost	1	0.5
Annual Cost	2	1

Table 5.12: Decision of Adopting VM - Comparison Matrix for DigitalOcean

DigitalOcean	Migration Cost	Annual Cost
Migration Cost	1	0.333
Annual Cost	3	1

Table 5.13: Decision of Adopting VM - Comparison Matrix for Internap

Internap	Migration Cost	Annual Cost
Migration Cost	1	3
Annual Cost	0.333	1

Table 5.14: Decision of Adopting VM - Comparison Matrix for Microsoft Azure

Microsoft Azure	Migration Cost	Annual Cost
Migration Cost	1	3
Annual Cost	0.333	1

Table 5.15: Decision of Adopting VM - Comparison Matrix for Rackspace

Rackspace	Migration Cost	Annual Cost
Migration Cost	1	1
Annual Cost	1	1

Table 5.16: Decision of Adopting VM - Resulting Super Matrix

	Migration Cost	Annual Cost	Migration Time	Cloud Sigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
Migration Cost	0	0	0	0.067	0.050	0.150	0.150	0.100
Annual Cost	0	0	0	0.133	0.150	0.050	0.050	0.100
Migration Time	0	0	0	0.200	0.200	0.200	0.200	0.200
CloudSigma	0.092	0.200	0.300	0	0	0	0	0
DigitalOcean	0.054	0.142	0.133	0	0	0	0	0
Internap	0.062	0.046	0.133	0	0	0	0	0
Microsoft Azure	0.233	0.046	0.275	0	0	0	0	0
Rackspace	0.058	0.062	0.158	0	0	0	0	0

Table 5.17: Decision of Adopting VM - Resulting Limit Matrix

	Migration Cost	Annual Cost	Migration Time	Cloud Sigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
Migration Cost	0	0	0	0.257	0.257	0.257	0.257	0.257
Annual Cost	0	0	0	0.243	0.243	0.243	0.243	0.243
Migration Time	0	0	0	0.500	0.500	0.500	0.500	0.500
CloudSigma	0.297	0.297	0.297	0	0	0	0	0
DigitalOcean	0.154	0.154	0.154	0	0	0	0	0
Internap	0.125	0.125	0.125	0	0	0	0	0
Microsoft Azure	0.278	0.278	0.278	0	0	0	0	0
Rackspace	0.146	0.146	0.146	0	0	0	0	0

Table 5.18: Decision of Adopting VM - Row Specific Limit Matrix Values

Node	Increase	Decrease
Migration Cost	0.0129	-0.0129
Annual Cost	-0.0129	0.0129
Migration Time	-0.0002	0.0001
CloudSigma	-0.0207	0.0210
DigitalOcean	-0.0183	0.0186
Internap	-0.0122	0.0119
Microsoft Azure	0.0511	-0.0509
Rackspace	-0.0151	0.0151

5.1.3 Decision of Adopting PaaS (Use Case 3)

The Use Case 3 (UC3) the scenario of adopting PaaS in Organization *O12* is evaluated, with alternative providers of Heroku, dotCloud, and AnnHarbour as shown in Table 5.20. Based on the technical requirements of *O12* these alternatives are evaluated with TOPSIS using five criteria. *Uptime* denotes the average available percentage value PaaS provided by respective alternative was available in a span of 30 days as measured by [95]. *RAM* denotes the configurable memory provided in MB. *Runtimes* denotes the number of supported programming languages. *Services* are additional services that are supported (for example databases), and *Add-ons* are additional other programs which can be used. In this scenario all these criteria have a positive impact and are weighted equally. Therefore, the highest ranked alternative as per TOPSIS is Heroku.

For ranking the alternatives from the business perspective the model in Figure 5.3 for ANP is constructed. In this case there is a self-loop on the *cost* cluster that allows to give relative priority to each criteria in a cluster. Here the criteria of *integration cost* is considered twice as important as *performance cost* (cf. Table 5.25). This is because for *O12* integrating the current legacy applications to the PaaS is more crucial, and therefore the associated cost has a bigger influence in the decision making. Also, comparison matrices (cf. Table 5.22- Table 5.24) are constructed based on the cost values and number of locations where server exists as obtained from [95].

Table 5.19: Decision of Adopting VMs - Element Specific Limit Matrix Values

Node	Connected Node	Increase	Decrease
Migration Cost	CloudSigma	0.0035	-
Migration Cost	DigitalOcean	0.0019	-
Migration Cost	Internap	0.0019	-
Migration Cost	Microsoft Azure	0.0043	-
Migration Cost	Rackspace	0.00185	-
Annual Cost	CloudSigma	-	0.0040
Annual Cost	DigitalOcean	-	0.0023
Annual Cost	Internap	-	0.0012
Annual Cost	Microsoft Azure	-	0.0030
Annual Cost	Rackspace	-	0.0017
Migration Time	CloudSigma	2.7403e-05	-
Migration Time	DigitalOcean	4.7268e-05	-
Migration Time	Internap	-	4.1077e-05
Migration Time	Microsoft Azure	-	0.0002
Migration Time	Rackspace	-	2.5285e-05
CloudSigma	Migration Cost	-	0.0047
CloudSigma	Annual Cost	-	0.0052
CloudSigma	Migration Time	-	0.0102
DigitalOcean	Migration Cost	-	0.0045
DigitalOcean	Annual Cost	-	0.0047
DigitalOcean	Migration Time	-	0.0087
Internap	Migration Cost	-	0.0031
Internap	Annual Cost	-	0.0025
Internap	Migration Time	-	0.0059
Microsoft Azure	Migration Cost	0.01786	-
Microsoft Azure	Annual Cost	0.0101	-
Microsoft Azure	Migration Time	0.0252	-
Rackspace	Migration Cost	-	0.0038
Rackspace	Annual Cost	-	0.0032
Rackspace	Migration Time	-	0.00754

For the alternatives of Heroku, dotCloud, and AnnHarbour, limit matrix shows the value of (0.335, 0.343, 0.322) respectively. Therefore, according to ANP dotCloud is the highest ranked alternative.

Table 5.20: Decision of Adopting PaaS - Input for TOPSIS

Alternatives	Uptime (%)	RAM (MB)	Runtimes	Services	Add-ons
Heroku	99.91	512	9	2	17
dotcloud	99.95	32	5	1	7
AppHarbor	99.99	512	1	3	33

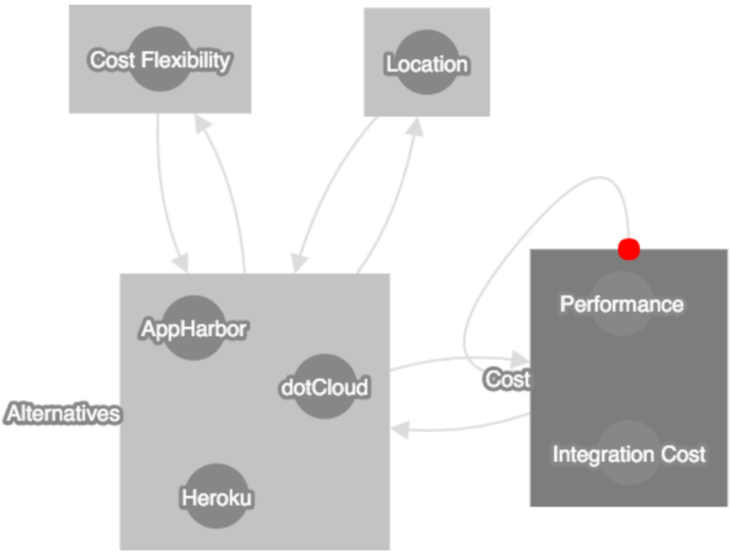


Figure 5.3: Decision of Adopting PaaS - ANP Model

Table 5.21: Decision of Adopting PaaS - Comparison Matrix for Cost Flexibility

Cost Flexibility	Heroku	dotCLoud	AppHarbour
Heroku	1	0.25	0.5
dotCLoud	4	1	2
AppHarbour	2	0.5	1

Table 5.22: Decision of Adopting PaaS - Comparison Matrix for Location

Location	Heroku	dotCLoud	AppHarbour
Heroku	1	2	1
dotCLoud	0.5	1	0.5
AppHarbour	1	2	1

Table 5.23: Decision of Adopting PaaS - Comparison Matrix for Integration Cost

Integration Cost	Heroku	dotCLoud	AppHarbour
Heroku	1	4	3
dotCLoud	0.25	1	0.5
AppHarbour	0.33	2	1

Table 5.24: Decision of Adopting PaaS - Comparison Matrix for Performance Cost

Performance Cost	Heroku	dotCLoud	AppHarbour
Heroku	1	5	0.5
dotCLoud	0.2	1	4
AppHarbour	2	0.25	1

Table 5.25: Decision of Adopting PaaS - Comparison Matrix for Cost

Cost	Performance Cost	Integration Cost
Performance Cost	1	0.5
Integration Cost	2	1

Table 5.26: Decision of Adopting PaaS - Resulting Super Matrix

	Location	Performance Cost	Integration Cost	Cost Flexibility	Heroku	dotcloud	AppHarbor
Location	0	0	0	0	0.083	0.083	0.083
Performance Cost	0	0	0	0	0.021	0.056	0.028
Integration Cost	0	0	0	0	0.062	0.028	0.056
Cost Flexibilty	0	0	0	0	0.083	0.083	0.083
Heroku	0.100	0.037	0.104	0.035	0	0	0
dotcloud	0.050	0.025	0.022	0.144	0	0	0
AppHarbor	0.100	0.022	0.040	0.071	0	0	0

Table 5.27: Decision of Adopting PaaS - Resulting Limit Matrix

	Location	Performance Cost	Integration Cost	Cost Flexibility	Heroku	dotcloud	AppHarbor
Location	0	0	0	0	0.333	0.333	0.333
Performance Cost	0	0	0	0	0.140	0.140	0.140
Integration Cost	0	0	0	0	0.193	0.193	0.193
Cost Flexibilty	0	0	0	0	0.333	0.333	0.333
Heroku	0.335	0.335	0.335	0.335	0	0	0
dotcloud	0.343	0.343	0.343	0.343	0	0	0
AppHarbor	0.322	0.322	0.322	0.322	0	0	0

However, now the results of TOPSIS and ANP do not match and therefore a tradeoff is necessary. Since TrAdeCIS allows to select the best technical alternative at trade-offs of business values, priority of criteria are altered in the ANP model. Row specific values of limit matrices are obtained by increasing (*inc*) and decreasing (*dec*) the original super matrix as per Algorithm 1. This process is repeated for each row and the values corresponding to Heroku (as this was the highest ranked alternative according to TOPSIS) in these limit matrices are shown in Table 5.28.

Table 5.28: Decision of Adopting PaaS - Row Specific Limit Matrix Values

Node	Increase	Decrease
Location	0.0024	-0.0024
Performance Cost	0.0038	-0.0039
Integration Cost	0.0139	-0.0139
Cost Flexibility	-0.0142	0.01430
Heroku	0.0464	-0.0457
dotcloud	-0.0257	0.0255
AppHarbor	-0.0219	0.0219

Table 5.28 shows that increasing Heroku in terms of its interconnected node is the most beneficial (highest value corresponds to Heroku) for ranking Heroku on top as per ANP. Table 5.29 shows values of limit matrices that are obtained by increasing or decreasing only one element at time in the original super matrix.

This is done only for positive values in Table 5.28. For example, as *Location* has positive value in Table 5.28, three values are obtained in 5.29 corresponding to the interrelation of Location to Heroku, Location to dotCloud and Location to AppHarbour.

Table 5.29: Decision of Adopting PaaS - Element Specific Limit Matrix Values

Node	Changed by	Increase	Decrease
Location	Heroku	0.0009	-
Location	dotcloud	0.0009	-
Location	AppHarbor	0.0008	-
Performance Cost	Heroku	0.0013	-
Performance Cost	dotcloud	0.0014	-
Performance Cost	AppHarbor	0.0011	-
Integration Cost	Heroku	0.0055	-
Integration Cost	dotcloud	0.0041	-
Integration Cost	AppHarbor	0.0045	-
Cost Flexibility	Heroku	-	0.0051
Cost Flexibility	dotcloud	-	0.0043
Cost Flexibility	AppHarbor	-	0.0042
Heroku	Location	0.0156	-
Heroku	Performance Cost	0.0070	-
Heroku	Integration Cost	0.0158	-
Heroku	Cost Flexibility	0.0109	-
dotcloud	Location	-	0.0064
dotcloud	Performance Cost	-	0.0029
dotcloud	Integration Cost	-	0.0035
dotcloud	Cost Flexibility	-	0.0114
AppHarbor	Location	-	0.0080
AppHarbor	Performance Cost	-	0.0026
AppHarbor	Integration Cost	-	0.0038
AppHarbor	Cost Flexibility	-	0.0066

This leads to the identification of the node that is interrelated to Heroku; when changed in terms of its associated priority will make Heroku the highest ranked alternative. In this example, as Heroku associated with *Integration Cost* has highest positive value, change in priority of *Integration Cost* will lead to the desired ranking. Therefore, by adjusting the importance of *integra-*

tion cost to be 4 times higher than *performance cost* in the *cost* cluster, both algorithms give the same result of Heroku. Also, as per the requirements of *O12*, *integration cost* is more important than *performance cost*, therefore, further increase in this priority reinstates the requirements.

5.1.4 Decision of Adopting Resource as a Service (Use Case 4)

For Use Case 4 (UC4) the decision is regarding Resource as a Service (RaaS), and it entails high complexity owing to higher number of interrelations between the factors from business perspective. The input values for TOPSIS, as shown in Table 5.30, are obtained with respect to alternatives of Virtual Machines (VM) that are offered by 5 different providers for organization *O2*. The technical requirements remain the same as evaluated in use case 2. Therefore, with TOPSIS highest ranked alternative is that of Microsoft Azure.

Table 5.30: Decision of Adopting Resource as a Service - Input for TOPSIS

Alternatives	vCPU	RAM (GB)	Storage (GB SSD)
Cloud Sigma	1	2	50
Digital Ocean	2	2	40
Internap	1	4	20
Microsoft Azure	1	3.5	50
Rackspace	2	2	40

As shown in the ANP model (cf. Figure 5.4) from business perspective the alternatives are evaluated by interdependent factors of *time*, *cost*, *location* of data centers, *carbon footprint*, and *legal and regulative compliance*. As discussed in Chapter 3, migration time effects the cost of the adopted service, and location where the data centers or servers are located decide whether the service is compliant to legal and regulative requirements.

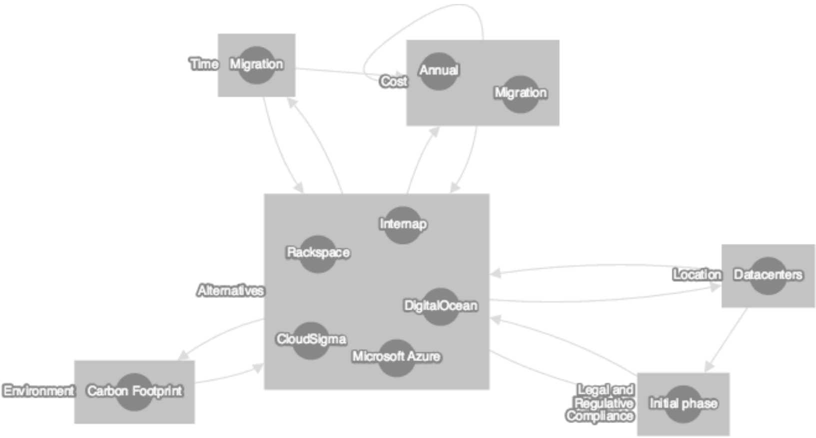


Figure 5.4: Decision of Adopting Resource as a Service - ANP Model

Table 5.31: Decision of Adopting Resource as a Service - Comparison Matrix for Migration Time

(a) Use Case 4 - Comparison Matrix for Migration Time and Alternatives

Migration Time	Cloud Sigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
Cloud Sigma	1	2	2	2	1
Digital Ocean	0.5	1	1	0.5	1
Internap	0.5	1	1	0.5	1
Microsoft Azure	0.5	2	2	1	3
Rackspace	1	1	1	0.33	1

(b) Decision of Adopting Resource as a Service - Comparison Matrix for Migration Time and Cost

Migration Time	Migration Cost	Annual Cost
Migration Cost	1	5
Annual Cost	0.2	1

Table 5.32: Decision of Adopting Resource as Service - Comparison Matrix for Cost

Cost	Migration Cost	Annual Cost
Migration Cost	1	0.3
Annual Cost	3	1

Table 5.33: Decision of Adopting Resource as a Service - Comparison Matrix for Location

(a) Use Case 4 - Comparison Matrix for Location and Alternatives

Location	Cloud Sigma	Digital Ocean	Internap	Microsoft Azure	Rackspace
Cloud Sigma	1	2	2	2	1
Digital Ocean	0.5	1	1	0.5	1
Internap	0.5	1	1	0.5	1
Microsoft Azure	0.5	2	2	1	3
Rackspace	1	1	1	0.33	1

(b) Decision of Adopting Resource as a Service - Comparison Matrix for Location and Legal and Regulative Compliance

Location	Legal and Regulative Compliance
Legal and Regulative Compliance	1

Table 5.34: Decision of Adopting Resource as Service - Cluster Matrix

Cluster Matrix	Alternatives	Cost	Time	Environment	Location	Legal and Regulative Compliance
Alternatives	1	1	1	1	1	1
Cost	1	1	3	3	1	3
Time	1	0.33	1	1	0.25	1
Environment	1	0.33	1	1	0.25	1
Location	1	1	4	4	1	1
Legal and Regulative Compliance	1	0.33	1	1	1	1

This interdependency of factors is also reflected in the comparison matrices, wherein relative priorities of all interconnected factors are entered as input to ANP (cf. Table 5.31, Table 5.33). Table 5.31a and Table 5.33a represent the relative values of all alternatives with respect to migration time and number of locations where data centers exists as measured by [22]. In addition Table 5.31b represents impact of migration time on *migration cost* is five times more than its impact on *annual cost.* Table 5.33b represents impact of *location* on *legal and regulative compliance.*

As *legal and regulative compliance* does not have multiple subfactors, this impact is denoted by one. In this case there is a self-loop on the *cost* cluster that allows to give relative priority to each criteria in a cluster. Here the criteria of *annual cost* is considered thrice as important as *migration cost* (cf. Table 5.32). This is because for *O2* main objective of adopting cloud-based services is that of reduction in annual cost associated with IT infrastructure. Therefore, *O2* prefers an alternative with lower *annual cost* even if the initial *cost of migrating* data to cloud is high. In addition, based on the requirements of *O2*, the clusters of factors are allotted different priorities using GUI of TrAdeCIS as shown in Table 5.34. *Cost* is three times more important than *migration time*, *carbon footprint*, and *legal and regulative compliance*. Also, number of places where severs are placed, is four times more important than *migration time* and *carbon footprint*. Hence making the cluster of *cost* being valued the highest.The resulting super matrix is shown in Table 5.35 calculated from Eigen vectors of comparison matrices, and the resulting limit matrix is shown in Table 5.36. Based on the values of limit matrix for the alternatives of CloudSigma, DigitalOcean, Internap, Microsoft Azure, and Rackspace are (0.099, 0.086, 0.081, 0.097, 0.077), CloudSigma is ranked the highest as per ANP. Because the results of TOPSIS (Microsoft Azure) and ANP (CloudSigma) do not match, establishing trade-offs is now suggested by the system. TrAdeCIS proposes to select the best technical alternative at trade-offs of business factors. Row specific values of limit matrices are obtained by increasing (*inc*) and decreasing (*dec*) original super matrix as per Algorithm 1. This process is repeated for each row and the values corresponding to Microsoft Azure (as this was the highest ranked alternative according to TOPSIS) in these limit matrices are shown in Table 5.37. Table 5.37 shows that increasing Microsoft Azure in terms of its interconnected node is the most beneficial (highest value corresponds to Microsoft Azure) for ranking Microsoft Azure on top as per ANP.

Table 5.35: Decision of Adopting Resource as Service - Resulting Super Matrix

	Migration Cost	Annual Cost	Migration Time	Carbon Foot print	Location	Legal and Regulative	Cloud Sigma	Digital Ocean	Inter nap Azure	Micro- -soft	Rack space
Migration Cost	0	0	0	0	0	0	0.016	0.016	0.016	0.016	0.016
Annual Cost	0	0	0	0	0	0	0.016	0.016	0.016	0.016	0.016
Migration Time	0	0	0	0	0	0	0.031	0.031	0.031	0.031	0.031
Carbon Footprint	0	0	0	0	0	0	0.031	0.031	0.031	0.031	0.031
Location	0	0	0	0	0	0	0.031	0.031	0.031	0.031	0.031
Legal and Regulative	0	0	0	0	0	0	0.031	0.031	0.031	0.031	0.031
Cloud Sigma	0.012	0.078	0.030	0.013	0.048	0.024	0	0	0	0	0
Digital Ocean	0.007	0.055	0.013	0.019	0.055	0.022	0	0	0	0	0
Internap	0.008	0.018	0.013	0.018	0.031	0.036	0	0	0	0	0
Microsoft Azure	0.030	0.018	0.028	0.019	0.086	0.013	0	0	0	0	0
Rackspace	0.008	0.024	0.016	0.032	0.031	0.036	0	0	0	0	0

Table 5.36: Decision of Adopting Resources as - Resulting Limit Matrix

	Migration Cost	Annual Cost	Migration Time	Carbon Footprint print	Location	Legal and Regulative	Cloud Sigma	Digital Ocean	Inter nap	Micro- -soft Azure	Rack space
Migration Cost	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
Annual Cost	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Migration Time	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
Carbon Footprint	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
Location	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
Legal and Regulative	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194
Cloud Sigma	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
Digital Ocean	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
Internap	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
Microsoft Azure	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
Rackspace	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077

Table 5.38 shows values of limit matrices that are obtained by increasing or decreasing only one element at time in the original super matrix. This is done only for positive values in Table 5.37. For example, as *Migration Cost* has positive value in Table 5.37 in the case of increase, six values are obtained in 5.29 corresponding to the interrelation of *Migration Cost* to every alternatice. This

leads to the identification of the node that is interrelated to Microsoft Azure; when changed in terms of its associated priority will make Microsoft Azure the highest ranked alternative.

Table 5.37: Decision of Adopting Resource as Service - Element Specific Limit Matrix Values

Node	Increase	Decrease
Migration Cost	0.0046	-0.0047
Annual Cost	-0.0027	0.0028
Migration Time	0.0008	-0.0010
Carbon Footprint	-0.0008	0.0007
Location	-0.0011	0.0011
Legal and Regulative	-0.0032	0.0033
Cloud Sigma	-0.0040	0.0040
Digital Ocean	-0.0038	0.0038
Internap	-0.0038	0.0038
Microsoft Azure	0.0176	-0.0175
Rackspace	-0.0040	0.0040

In this example, as Microsoft Azure associated with *Legal and Regulative* has highest positive value, change in priority of *Legal and Regulative* will lead to the desired ranking. It can be seen from Table 5.37 that the increase of the importance of Microsoft Azure is the most rewarding.

5.1.5 Performance Test Results of TrAdeCIS

In order to test the scalability of TOPSIS and ANP, this section evaluates the performance with respect to time taken to rank the alternatives using these two algorithms. As shown in Test code 5.1, the performance test is done for 1000 executions for both TOPSIS and ANP. All the performance tests are executed on a system with a 2.6 GHz Intel Core i5 CPU, 8 GB 1600 MHz DDR3 RAM and an Intel HD Graphics 4000 1536 MB graphics card.

Table 5.38: Decision of Adopting Resource as Service - Element Specific Limit Matrix Values

Node	Changed by	Increase	Decrease
Migration Cost	Migration Time	0.0010	-
Migration Cost	Cloud Sigma	0.0008	-
Migration Cost	Digital Ocean	0.0006	-
Migration Cost	Internap	0.0007	-
Migration Cost	Microsoft Azure	0.0009	-
Migration Cost	Rackspace	0.0008	-
Annual Cost	Migration Time	-	0.0005
Annual Cost	Cloud Sigma	-	0.0004
Annual Cost	Digital Ocean	-	0.0003
Annual Cost	Internap	-	0.0004
Annual Cost	Microsoft Azure	-	0.0004
Annual Cost	Rackspace	-	0.0004
Migration Time	Cloud Sigma	0.0002	-
Migration Time	Digital Ocean	0.0002	-
Migration Time	Internap	0.0002	-
Migration Time	Microsoft Azure	0.0002	-
Migration Time	Rackspace	0.0002	-
Carbon Footprint	Cloud Sigma	-	0.0002
Carbon Footprint	Digital Ocean	-	0.0001
Carbon Footprint	Internap	-	0.0002
Carbon Footprint	Microsoft Azure	-	0.0002
Carbon Footprint	Rackspace	-	0.0002
Location	Cloud Sigma	-	0.0002
Location	Digital Ocean	-	0.0002
Location	Internap	-	0.0002
Location	Microsoft Azure	-	0.0002
Location	Rackspace	-	0.0002
Legal and Regulative	Location	-	0.0009
Legal and Regulative	Cloud Sigma	-	0.0005
Legal and Regulative	Digital Ocean	-	0.0004
Legal and Regulative	Internap	-	0.0004
Legal and Regulative	Microsoft Azure	-	0.0005
Legal and Regulative	Rackspace	-	0.0005
Cloud Sigma	Migration Cost	-	0.0006
Cloud Sigma	Annual Cost	-	0.0005
Cloud Sigma	Migration Time	-	0.0004
Cloud Sigma	Carbon Footprint	-	0.0006
Cloud Sigma	Location	-	0.0004
Cloud Sigma	Legal and Regulative	-	0.0010
Digital Ocean	Migration Cost	-	0.0005
Digital Ocean	Annual Cost	-	0.0004
Digital Ocean	Migration Time	-	0.0004
Digital Ocean	Carbon Footprint	-	0.0007
Digital Ocean	Location	-	0.0004
Digital Ocean	Legal and Regulative	-	0.0010
Internap	Migration Cost	-	0.0006
Internap	Annual Cost	-	0.0004
Internap	Migration Time	-	0.0005
Internap	Carbon Footprint	-	0.0007
Internap	Location	-	0.0004
Internap	Legal and Regulative	-	0.0011
Microsoft Azure	Migration Cost	0.0041	-
Microsoft Azure	Annual Cost	0.0014	-
Microsoft Azure	Migration Time	0.0028	-
Microsoft Azure	Carbon Footprint	0.0028	-
Microsoft Azure	Location	0.0030	-
Microsoft Azure	Legal and Regulative	0.0039	-
Rackspace	Migration Cost	-	0.0005
Rackspace	Annual Cost	-	0.0003
Rackspace	Migration Time	-	0.0004
Rackspace	Carbon Footprint	-	0.0009
Rackspace	Location	-	0.0005
Rackspace	Legal and Regulative	-	0.0011

Listing 5.1: Performance Test Code

```
def measure_topsis(alternatives, criteria, min_value=0,
    max_value=100, number_executions=1000):
        matrix = random.random_integers(min_value,
            max_value, (alternatives, criteria))
        weights = random.random_integers(1, 15, (1,
            criteria))
        effect = random.random_integers(0, 1, (1,
            criteria))
        result = 'TOPSIS{0} alternatives,{1} criteria
            average_runtime_over{2}:{3}s'
        print(result.format(alternatives, criteria,
            number_executions, time_function(service.
            topsis, number_executions, matrix, weights,
             effect)/number_executions))

def measure_anp(alternatives, criteria, number_executions
    =1000):
        super_matrix = random.random((alternatives+
            criteria, alternatives+criteria))
        result = 'ANP{0} alternatives,{1} criteria
            average_runtime_over{2}:{3}s'
        print(result.format(alternatives, criteria,
            number_executions, time_function(service.
            anp, number_executions, super_matrix,
            alternatives)/number_executions))
```

These executions are different in terms of every possible following input value that is related to factors and alternatives that TOPSIS and ANP require:

- Number of alternatives and criteria.
- Random performance values given for every alternative with respect to criteria in TOPSIS. These values range between 1 and 100000. These values are normalized within TOPSIS, and therefore higher values will not effect the execution time of the algorithm.
- Random priority values allotted for criteria, having random benefit/risk associated with it for TOPSIS. These values are also normalized within TOPSIS, and therefore execution time is not dependent on these values.
- Random values in super matrix generated for ANP.

- Random interrelations between the nodes and clusters of ANP. Higher the number of criteria and alternatives, more complex will be these interrelations. Therefore, effect of number of interrelations is measured by number of criteria and alternatives

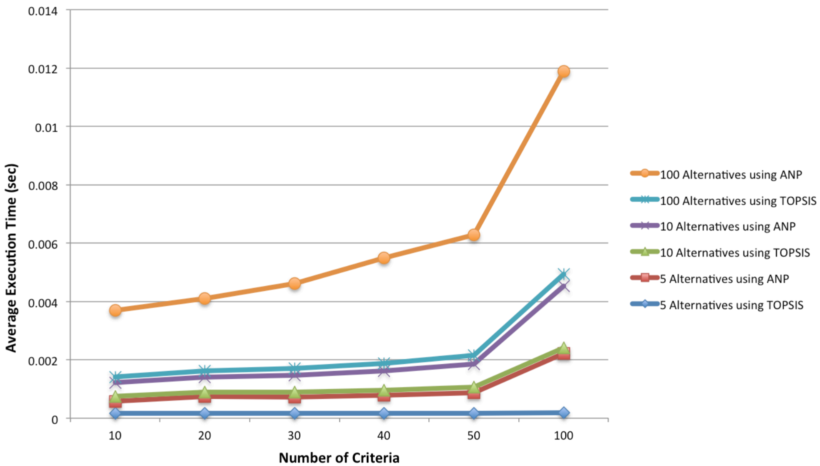


Figure 5.5: Average Time for Ranking Alternatives in 1000 Executions

Therefore, the scalability of TOPSIS and ANP is dependent only on the number of criteria and alternatives. As shown in graph (cf. Figure 5.5) TOPSIS scales better (lower execution time with same number of alternatives and criteria) than ANP. In ANP the execution time is dependent on the structure of the network formed with interrelation of criteria and alternatives. As shown with the line graph corresponding to time taken to rank 100 alternatives using ANP, execution time rises almost exponentially. This is because higher the number of nodes in a cluster, higher will be the interrelations and corresponding cluster matrices, which in turn leads to higher time in reaching a limit matrix. For example, when 1000 alternatives are evaluated with respect to 100 criteria, it needs to execution time of 0.7337 secs. Even though ANP does not scale as efficiently as TOPSIS, the total execution time to reach a quantitative decision of ranking 100 alternatives using 100 technical criteria, and 100 economical and organization criteria (which is the upper limit of factors based on the survey) is as optimal as 0.017 secs.

5.1.6 Guidelines Derived from Evaluation of TrAdeCIS

Based on the evaluation of use cases of cloud-based services following guidelines can be established to make decisions with TrAdeCIS:

- TrAdeCIS can be applied to decisions involving adoption of cloud-based services with multiple available alternatives and criteria.
- Once the alternatives are identified, criteria can be selected from the GUI developed for automated decision making using TrAdeCIS. These factors are listed along with their subfactors, which can be selected as per requirements of the organization. Actual measured values (having different units) can be entered as values for factors in TOPSIS as the algorithm normalizes the input. For ANP, relative priorities are to be entered by pair wise comparisons of interdependent factors. These relative priorities are to be calculated based on actual measured values corresponding to business factors, which ANP normalizes to calculate the final ranking.
- For TOPSIS number of criteria does not effect the performance and execution time of the decision. However, with ANP higher number of criteria results in higher number of comparison matrices. This results in higher execution time as the number of criteria increases.
- If the ranking obtained from TOPSIS and ANP do not match, trade-offs will have to be established. These trade-offs are based on change of priorities in factors from business perspective, as the best technical alternative has to be selected at

the trade-off of business value. This can be done by either calculating rank influence or marginal influence so that least number of changes in priorities of factors are required by decision maker to establish trade-offs.

5.2 Generalization of TrAdeCIS

TrAdeCIS is primarily developed to support organizations in the adoption of cloud-based services. However, this section evaluates the applicability of TrADeCIS to improve the decision making of technologies from other domains besides cloud-based services. This is illustrated by applying TrAdeCIS to Train Operating Companies (TOC) who need to make a decision of choosing the best technology to improve both voice- and data coverage on-board of trains. Even though a train journey can be a perfect time to answer a phone call or browse the Internet on a personal device (*e.g.,* smartphone, tablet, or laptop), coverage on trains is generally bad due to the attenuation by the train carriage and lack of coverage along the rail corridor. Three broad types of on-board systems exist to improve coverage on-board the train: IP-based data access points (*e.g.,* Wi-Fi), wideband repeaters, and small cells (*e.g.,* femto cells). These repeaters resolve the attenuation challenge, but they still require a connection to and from the wayside. Each of these solutions uses a mobile backhaul, thus, the provider of the on-board repeaters collaborates with an existing cellular network provider. This is, however, not the only option as other types of networks also can be used such as the network of a satellite network provider. In some cases even a dedicated network has been developed (*e.g.,* a WiMAX network). For the application of TrAdeCIS, these different choices form the alternative offerings. The TOC will also have a set of functional- and non-functional requirements to be matched with each of these solutions. Requirements from business perspective cover both organizational and economic aspects.

Validity of applicability with following use case where the decision takes the perspective of the TOC who is hoping to sell more tickets by providing the service. For the train-to-wayside connection, it is assumed that all on-board solutions use the same system: connection to mobile base stations (3G or beyond). The following alternatives are considered to be installed on-board of train:

- Option 1: Wireless Access Point (WAP)
- Option 2: Analog repeater
- Option 3: Femtocells

The technical requirements from these alternatives and their relative priorities are the following:

- Internet should be available to all passengers with a mobile device (Priority 1)
- Quality of voice calls should be improved for all passengers with a phone (Priority 2)
- Internet speed should be as high as possible (Priority 3)

Table 5.39: Use Case of TOC - Input for TOPSIS

Alternatives	Internet **A**vailability	Voice Coverage	Internet Speed
WAP	3	1	3
Analog Repeater	2	2	2
Femtocells	2	2	2

The ranking of the alternatives (cf. Table 5.39) is based on the performance values of these alternatives per factor obtained in [89]. These values are represented on a scale of 1-3 (chosen based on number of alternatives). Higher performance value of an alternative for a factor is mapped to a higher value in the chosen scale. For the factor of *availability*, WAP is ranked the highest and analog repeater and femtocells are at the same rank. Similar ranking is given to the alternatives for other two factors of *voice coverage* and *Internet speed* too. After applying TOPSIS to these alternatives per technical requirements, installing WAPs is ranked the highest.

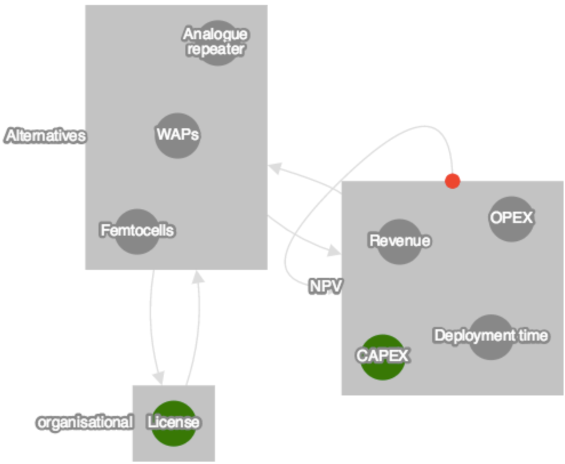


Figure 5.6: Use Case of TOC - ANP Model

From the financial/economic requirements perspective, ANP is used to model the decision as shown in Figure 5.6. *Net Present Value (NPV)* and use of *licensed spectrum* are two factors based on which alternatives are to be ranked. NPV, which should be positive as soon as possible, is of higher priority of the two. In addition, NPV is categorized into sub-factors of low *deployment time*, high *revenue*, low *capital expenditure*, and low *operational expenditure*. Also, all these sub-factors are associated with a contribution weightage in comparison to each other. This is represented with a self-loop and the respective weightage or priorities of these factors are entered in the corresponding comparison matrix (cf. Table 5.40). Also in terms of the organizational requirements, the TOC prefers to avoid the use of *licensed spectrum* (medium importance). The comparison matrices show the relative ranking of alternatives with respect to factors of *licensed spectrum* (cf. Table 5.41), *OPEX* (cf. Table 5.42), *CAPEX* (cf. Table 5.43), *deployment time* (cf. Table 5.44), and *revenue generated* (cf. Table 5.45). As the aim is to use avoid the use of *licensed spectrum*, WAPs are ranked (on the scale of 1-3, chosen based on number of alternatives) thrice better than femtocells and analog repeaters as shown in Table 5.41. This is because femtocells and analog repeater use licensed spectrum, whereas WAPs have unlicensed spectrum available. *Operating cost* is same for all the alternatives, and therefore all the alternatives are ranked equally in Table 5.42. In terms of *capital cost* Wi-Fi access points are cheaper than analog repeaters and femtocells [89]. As a femto gateway is a highly specialized, expensive device that can support hundreds of thousands of femtocell base stations, the deployment of a femtocell gateway cannot be justified in economic terms when this device has to be purchased for an on-train femtocell service alone [89]. Therefore, in Table 5.43 WAPs are ranked the highest as compared to repeaters and femtocells, and femtocells is ranked the lowest. Finally, in Table 5.45 WAPs are ranked the lowest as compared to other two alternatives as it is hard to charge directly, only data service are possible, passengers are not willing to pay for Wi-Fi, and it is possible to offer value added services [89]. The resulting super matrix, which is constructed from all the comparison matrices, is shown in Table 5.46. The highest ranked alternative from ANP as obtained in limit matrix (cf. Table 5.47) with a value of 0.428 is WAPs. Therefore, as the ranking obtained from both TOPSIS and ANP is the same, for the scenario of providing Internet and voice call connectivity on-board of train, WAP is the best alternative, and also, establishing trade-offs is not required.

Table 5.40: Use Case of TOC - Relative Priorities of Sub-factors of NPV

NPV	OPEX	CAPEX	Time	Revenue
OPEX	1	1	2	0.25
CPEX	1	1	2	0.25
Time	0.5	0.5	1	0.125
Revenue	4	4	8	1

Table 5.41: Use Case of TOC - Comparison Matrix for License

License	WAPs	Analog Repeater	Femtocells
WAPs	1	3	3
Analog Repeater	0.333	1	1
Femtocells	0.333	1	1

Table 5.42: Use Case of TOC - Comparison Matrix for OPEX

OPEX	WAPs	Analog Repeater	Femtocells
WAPs	1	1	1
Analog Repeater	1	1	1
Femtocells	1	1	1

Table 5.43: Use Case of TOC - Comparison Matrix for CAPEX

CAPEX	WAPs	Analog Repeater	Femtocells
WAPs	1	2	3
Analog Repeater	0.5	1	2
Femtocells	0.333	0.5	1

Table 5.44: Use Case of TOC - Comparison Matrix for Time

Time	WAPs	Analog Repeater	Femtocells
WAPs	1	0.5	1.5
Analog Repeater	2	1	3
Femtocells	0.666	0.333	1

Table 5.45: Use Case of TOC - Comparison Matrix for Revenue

Revenue	WAPs	Analog Repeater	Femtocells
WAPs	1	0.5	0.333
Analog Repeater	2	1	2
Femtocells	3	0.5	1

Table 5.46: Use Case of TOC - Resulting Super Matrix

	OPEX	CAPEX	Time	Revenue	License	WAPs	Analog Repeater	Femtocells
OPEX	0	0	0	0	0	0.083	0.083	0.083
CAPEX	0	0	0	0	0	0.083	0.083	0.083
Time	0	0	0	0	0	0.083	0.083	0.083
Revenue	0	0	0	0	0	0.083	0.083	0.083
License	0	0	0	0	0	0.333	0.333	0.333
WAPs	0.05	0.041	0.021	0.308	0.425	0	0	0
Analog Repeater	0.05	0.081	0.041	0.154	0.425	0	0	0
Femtocells	0.05	0.027	0.014	0.154	0.142	0	0	0

Table 5.47: Use Case of TOC - Resulting Limit Matrix

	OPEX	CAPEX	Time	Revenue	License	WAPs	Analog Repeater	Femtocells
OPEX	0	0	0	0	0	0.125	0.125	0.125
CAPEX	0	0	0	0	0	0.125	0.125	0.125
Time	0	0	0	0	0	0.125	0.125	0.125
Revenue	0	0	0	0	0	0.125	0.125	0.125
License	0	0	0	0	0	0.5	0.5	0.5
WAPs	0.428	0.428	0.428	0.428	0.428	0	0	0
Analog Repeater	0.409	0.409	0.409	0.409	0.409	0	0	0
Femtocells	0.164	0.164	0.164	0.164	0.164	0	0	0

Therefore, it can be concluded based on this illustration that TrAdeCIS can be used to make adoption decision of any technology. The only requirement for this methodology to be applicable is that the decision must involve multiple alternative solutions which can be evaluated on different criteria. Also, as these algorithms normalizes the input values it allows entering input data in different measurement units for quantitative factors, and for qualitative factors relative ranking can be taken as input.

5.3 Temporal Influences on Factors

As the adoption decision is to be taken before the technology is deployed or adopted, the input performance values for each factor in TrAdeCIS and IAMCIS are assumed to be static. However, as the factors are interrelated, change in value of one affects the performance values of other interrelated factors. For example, the time-based graph shown in Figure 5.7 explains 4 scenarios depicting the implications of backing up data with respect to associated cost. Scenario 1 and 2 show that cost and backup are positively related to each other if there is no external influence (*e.g.,* data loss). Increase in backup will imply higher cost for organization, and if CSP does not offer backup or decreases the backup, cost will decrease for organization. Scenario 3 depicts the trend of these two factors in case of data loss. If there is no back up (depicted by decreasing trend of backup), data loss can have huge cost implications. This additional cost is associated not only with disaster recovery mechanisms that have to be applied (recovering lost data can require high investments), but also with the loss of potential future revenues due to unavailability of service. Therefore, depending on different turn of events the performance of an alternative would vary.

Also qualitative factors are interrelated as shown in Figure 5.8 for the example of interrelations between standards and vendor lock-in. If there are no common standards or if CSPs use more and more proprietary solutions for developing cloud services, the issue of interoperability will increase, leading to higher risk of

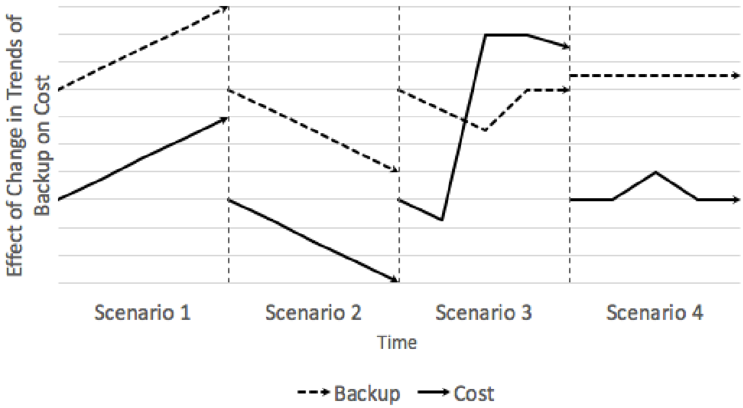


Figure 5.7: Time-based Graphs for Costs Relating to Backup

vendor lock-in and vice versa (cf. Scenario 1 and 2, Figure 5.8). One of the major motivations for CSPs to increase standards in CC can be that of optimization of workload and utilization ratio. Therefore, Scenario 3, depicts the case where vendor lock-in decreases but then becomes steady after a point. The only reason, as explained in Chapter 3, where the vendor lock-in might completely vanish can be because of interference of regulators.

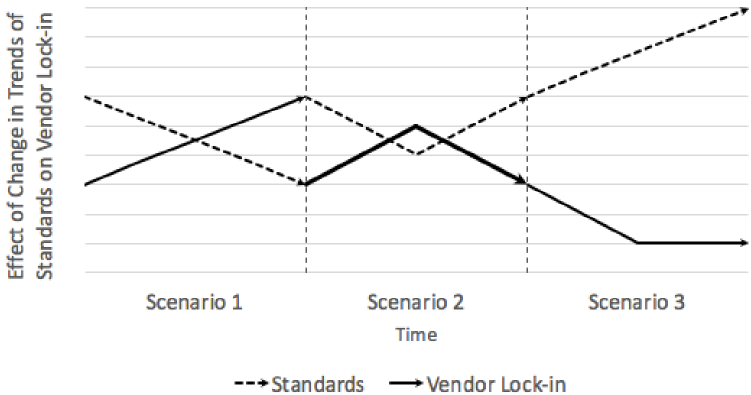


Figure 5.8: Time-based Graphs for Vendor Lock-in Relating to Standards

For TrAdeCIS including the factor of time translates into the following:

- Priority of factors can change with time.
- Change in value of one factor will have ripple effect onto other interrelated factors as well.
- TOPSIS and ANP will have to include multiple input values of every alternative depending on changes expected per factor for each instance of time.

However, there exist the following issues that make the inclusion of time factor in TrADeCIS too complex:

- Currently, TrADeCIS for every alternative includes measured values for quantitative factors, and relative ranking for the qualitative factors (discrete values). With the inclusion of time, these values will have to be predicted, which might compromise the accuracy of the decision made using TrAdeCIS.
- Also, some of the factors might see change in its value as a continuous function for some interval of time. Inclusion of such continuous functions in TrAdeCIS is not possible. This is because of the inability of algorithms of TOPSIS and ANP to take continuous input values.

Thus, to include the dynamic values in TrAdeCIS, TOPSIS and ANP have to be changed so that the input values can be expressed as interval numbers, fuzzy values, or interval-valued fuzzy values for each period of time. Finally, all those values will have to be aggregated to find out the final ranking of the alternatives. For IAMCIS (impact methodology) Equation 4.2 and Equation 4.3 can be altered as shown in Equation 5.1 and Equation 5.2 to include temporal influences. This is based on different performance values expected per factor at different instance(s) or interval(s) of time. The complexity associated with inclusion of temporal factor in IAMCIS is that of accurately predicting all possible values, and the time frame for which these value will persist for every relevant factor that is considered to evaluate the cloud-based service. Based on this, the associated loss (l_{ij_t}) and probability (p_{ij_t}) of expected value of factor i of component j not being fulfilled will change for different time (t) instances. Also, the total time frame (T) for which the impact has to predicted must be known/decided in advance.

$$I = \sum_{1 \leq i \leq n} \sum_{1 \leq j \leq m} w_{ij} \cdot (\sum_{1 \leq t \leq T} (l_{ij_t} \cdot p_{ij_t})) \tag{5.1}$$

$$I_{sev} = I \div \Big(\sum_{1 \leq i \leq n} \sum_{1 \leq j \leq m} w_{ij} \cdot (\sum_{1 \leq t \leq T} ((l_{ij_t})_{max} \cdot (p_{ij_t})_{max}) \Big) \tag{5.2}$$

5.4 Chapter Summary

By evaluating the results obtained in this chapter, implementation of TrAdeCIS was deemed to complement this thesis' first two major contributions – case study and identification of relevant factors and its interrelations, and quantified methodology of TrAdeCIS – in terms of a successful third major contribution. In terms of functionality and feasibility, the implementation has proven to be fully functional not only for cloud-based services but also for any other technology. Performance evaluation of the implementation of TrAdeCIS showed that the system is scalable to include all the factors that were identified from case studies (100 technical criteria, and 100 economical and organization criteria). It represents the first and only fully executable implementation of quantitative methodology for decision making of adopting a new technology in an organization.

6

Summary, Conclusions, and Future Work

THIS thesis has proposed and investigated several key aspects involved in quantifiable decision making of adopting new technology (mainly that of cloud computing) in an organization, which was largely unexplored before this thesis. Driven by the current observed status quo in decision analytics of adopting a new technology in an organization, the respective hypothesis and purpose of this thesis have been termed. As for the status quo, decision analytics of cloud computing adoption is based on ad-hoc methods and do not analyze quantitatively all the relevant factors for making such a decision. This thesis presents an important step in reaching this goal, by focussing on three following aspects, namely (a) identifying and structuring the list of relevant factors from technical, economical, and organizational factors, (b) developing and evaluating a fully quantified trade-off based decision methodology to make such decisions of adopting a new technology, and (c) developing and evaluating a quantified impact methodology to predict the impact on organization of a new technology. This thesis has shown the practicality of methodology developed in a single, web-based platform, called TrAdeCIS.

The main components of TrAdeCIS comprises of identification and modeling of requirements (factors), ranking of alternatives per factor, and establishing trade-offs. A list of 102 factors (from technical, economical, and organizational perspective) were identified on which cloud-based services can be evaluated. This was accomplished through exploratory research which consisted of extensive surveys conducted with 17 organizations from varied domains and expertise, and review of existing literature. In addition, interrelations amongst these factors were explored and modeled. These interrelations were categorized as “Parent of” and “Influences” interrelations. These interrelations are relevant as change in value of one factor can have an effect on several other related factors, thereby having greater impact on the decision of adopting best available cloud-based service. Factors such as that of legal and regulative compliance are qualitative in nature, and are hard to be quantified, which makes its modeling in decision model difficult. Therefore, specific GRL based modeling was performed and illustrated for modeling and ranking of alternatives for qualitative factors.

TrAdeCIS ranks all available alternatives from technical and business perspective using the algorithms of TOPSIS and ANP respectively. These algorithms incorporate the modeled interrelations of all relevant factors, relative ranking of alternatives for each qualitative and quantitative factor, and relative priorities of factors in ranking the alternatives. In cases when different rankings are obtained from technical and business perspectives, establishing trade-offs through TrAdeCIS allows a decision maker to select the best alternative from technical perspective at a trade-offs of business factors. These trade-offs are measured in terms of alterations required in priorities of business factors so that the rankings of alternatives obtained from both technical and business factors match.

The use case-driven evaluation of the system developed focuses in scenarios with variations in number of alternatives, number of criteria, and their interrelations. The system of TrAdeCIS shows its ability to scale, even with high a number of alternatives and criteria. The complete decision with as many as 100 criteria both in TOPSIS and ANP along with 100 alternatives takes 0.017 seconds to execute. For ANP the structure chosen and interconnections of the factors influences these time it takes to rank the alternatives. The application has been published in [39]. Validity and applicability of TrAdeCIS to the decisions involving other domains has been evaluated with the decision of choosing the best technology to improve both voice and data coverage on-board of trains. This evaluation concludes that TrAdeCIS is applicable to decision of adopting of any technology if the decision includes multiple alternative solutions that are to be evaluated on multiple criteria.

6.1 Contributions

This thesis made the following contributions and addresses the respectively associated challenges:

Contribution 1: Survey to collect relevant factor – This thesis conducted survey with 17 organizations, as part of research questions R1.1 and R2.1, to identify factors and model any interrelations that might exists amongst these factors. This survey is done in conjunction with literature review, to provide holistic and complete view of relevant factors for the decision of adopting cloud-based services. These hence identified 102 factors are categorized into the category of technical, economical, and organizational factors. In addition XML based taxonomy is being developed, where-in any possible interrelations between these factors are being modeled. Therefore, this taxonomy can be used as a basis for completely evaluating all alternative cloud-based solutions. Finally, for ranking the alternatives with respect to qualitative factors, GRL based modeling of such factors is performed. This modeling ranks the alternatives based on their respective fulfillment of number of sub-goals of each qualitative factor (modeled as goal).

Contribution 2: Quantitative decision methodology – The thesis developed, designed, and implemented a quantified trade-offs based decision methodology to make an accurate and precise decision based on the research question R1.2. As the algorithms of TOPSIS and ANP normalizes the input values, and allows entering relative ranking (required for qualitative factors), this methodology is applicable to any decision. Also, the requirements or factors based on which decision is achieved can have different measurement units, or can be qualitative. The methodology accommodates the presence of conflicting factors by allowing a decision maker to make trade-offs while making a decision. This trade-off allows to select the best technical alternative at a trade-off of business value as per hypothesis H1. This thesis has automated TrAdeCIS and implemented a prototype to recommend a user possible trade-offs if the ranking of alternatives is not same from technical and business perspectives. Trade-offs are established by measuring the changes required in priorities of economical and organizational factors. TrAdeCIS is scalable to high number of alternatives, factors, and their associated interrelations. This allows modeling of real-world complexities involved in such a decision making.

Contribution 3: Impact Prediction – Once the best alternative is identified, this thesis analyzes the importance of predicting the impact an alternative will have on an organization as stated in hypothesis H2. This prediction is specifically important in case of any unexpected future failure in a service, with respect to any factor that evaluates the service. The developed methodology of impact prediction corresponds to research question R2.2, and quantitatively evaluates the impact based on probability of failure and its associated loss.

Contribution 4: Generalization of TrAdeCIS – This thesis also evaluated the applicability of TrAdeCIS to other domains besides cloud-based services. This was done successfully with the use case of providing Internet on-board in trains. Therefore, the methodology of TrAdeCIS that is developed, implemented, and automated within this thesis can be applied to all decisions with low level complexity such a purchasing a car to highly complex decisions of adopting cloud-based services in an organization.

In conclusion, the qualitative analysis of those four objectives raised initially reveals that all objectives have been met successfully. This means that in addition to the set of effectively addressed challenges and gaps, the contributions achieved in this thesis provide sufficient support for the automation of decision making and replacing the current ad-hoc decisions with respect to cloud-based services. The evaluation of the prototype implemented concluded that TrAdeCIS is scalable to large number of alternatives, factors, and their associated interrelations. Also, establishing trade-offs automatically with TrADeCIS ensures quantified decisions are achieved encompassing conflicting and interdependent requirements. This allows modeling of real-world complexities involved in such a decision making. Furthermore, the developed methodology is extensible with respect to a wider scope in terms of technology domains and their requirements, in principle. The only requirement for this methodology to be applicable is that the decision must involve multiple alternative solutions which can be evaluated on different factors.

6.2 Future Work

The development and evaluation of relevant factors, their interrelations, and ranking of alternatives using technical, economical, and organizational factors are important steps of the developed quantified trade-offs-based decision methodology to adopt a new technology. However, open research questions still remain in this domain.

Automating the process of feeding performance values of different alternatives into TrAdeCIS will reduce the human intervention. This can be achieved by linking TrAdeCIS to a system (*e.g.,* Cloud Harmony Inc [22]) to fetch such values. In addition, TrADeCIS can include dynamic interrelations of factors and their time specific values. This will ensure that the decision is not just valid for the instance at which it is made, but is rather valid for a time frame for which values and their changes with respect to time are included.

In order to improve the current methodology fuzzy triangle numbers [60] can be included. This will solve decision problems that have unquantifiable, incomplete and non-obtainable input values. A fuzzy set is a class of objects with a continuum of grades of membership. Linguistic terms are represented by membership functions, valued in the real unit interval, which translates the vagueness and imprecision of input values [59]. This shall imply inclusion of Fuzzy-modified-TOPSIS and Fuzzy-modified-ANP instead of the current implemented algorithms. The final step would be to deploy these changes and evaluate the validity of new dynamic TrAdeCIS for different use cases that can encompass decisions of different domains and technologies.

A
XML Taxonomy

This appendix displays complete XML taxonomy that was developed within this thesis to structure all the relevant factors analyzed from exploratory research (cf. Chapter 3) from technical, economical, and organizational factors. This taxonomy also models all the interrelations of the factors that are modeled within this thesis.

Listing A.1: XML Taxonomy for Identified Factors Affecting Cloud Adoption

```
<?xml version=”1.0” encoding=”UTF8”?>
<!DOCTYPE TAXONOMY [
<!ELEMENT TAXONOMY (FACTORS+,RELATIONS?)>
<!ELEMENT FACTORS (FACTOR+)>
<!ELEMENT FACTOR (NAME, DEFINITION, VALUETYPE, TENDENCY,
      SUBFACTORS?)>
<!ELEMENT NAME (#PCDATA)>
<!ELEMENT DEFINITION (#PCDATA)>
<!ELEMENT SUBFACTORS (FACTOR+)>
<!ELEMENT VALUETYPE (#PCDATA) >
<!ELEMENT TENDENCY (#PCDATA)>

<!ELEMENT RELATIONS (RELATION+)>
<!ELEMENT RELATION EMPTY>


<!ATTLIST FACTORS CATEGORY (Economical|Organizational|Technical) #
      REQUIRED>
<!ATTLIST FACTOR FACTORID ID #REQUIRED>
<!ATTLIST RELATION RELATIONID ID #REQUIRED>
<!ATTLIST RELATION FACTOR1 IDREF #REQUIRED>
<!ATTLIST RELATION FACTOR2 IDREF #REQUIRED>
]>


<TAXONOMY>
   <FACTORS CATEGORY=”Technical”>
      <FACTOR FACTORID=”T1”>
         <NAME>Accessibility</NAME>
         <DEFINITION>Difficulty to access a service</DEFINITION>
         <VALUETYPE>List</VALUETYPE>
         <TENDENCY>higher</TENDENCY>
      </FACTOR>
      <FACTOR FACTORID=”T2”>
         <NAME>Application Lifecycle Management</NAME>
         <DEFINITION>The different phases of software development, from
               planning to retirement</DEFINITION>
       <VALUETYPE>List</VALUETYPE>
         <TENDENCY>higher</TENDENCY>
         <SUBFACTORS>
            <FACTOR FACTORID=”T2_1”>
               <NAME>Patching</NAME>
               <DEFINITION>Patchability of Application</DEFINITION>
           <VALUETYPE>List</VALUETYPE>
             <TENDENCY>higher</TENDENCY>
          </FACTOR>
            <FACTOR FACTORID=”T2_2”>
               <NAME>Upgrades</NAME>
               <DEFINITION>Upgradability of Application</DEFINITION>
               <VALUETYPE>List</VALUETYPE>
             <TENDENCY>higher</TENDENCY>
            </FACTOR>
         </SUBFACTORS>
      </FACTOR>
      <FACTOR FACTORID=”T3”>
         <NAME>Availability</NAME>
         <DEFINITION>Time a service is accessible and usable by an authorized
               entity as percentage (total_time/
               time_service_is_accessible_and_usable)</DEFINITION>
         <VALUETYPE>Range</VALUETYPE>
       <TENDENCY>higher</TENDENCY>
      </FACTOR>
```

```xml
    <FACTOR FACTORID=”T4”>
        <NAME>Backup</NAME>
        <DEFINITION>Redunant copies of data, to protect against data loss</DEFINITION>
     <VALUETYPE>Numeric</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID=”T5”>
        <NAME>Complexity</NAME>
        <DEFINITION>Difficulty to understand and use new technology</DEFINITION>
     <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
        <SUBFACTORS>
            <FACTOR FACTORID=”T5_1”>
                <NAME>Frustration</NAME>
                <DEFINITION>Frustration caused by complex system</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
              <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T5_2”>
                <NAME>Flexibility</NAME>
                <DEFINITION>Rigidness of system, i.e. if there are multiple ways to achieve the same goal</DEFINITION>
           <VALUETYPE>List</VALUETYPE>
              <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T5_4”>
                <NAME>Task Adequacy</NAME>
                <DEFINITION>Adequacy of system to complete a given goal</DEFINITION>
           <VALUETYPE>List</VALUETYPE>
              <TENDENCY>lower</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T5_5”>
                <NAME>Expectation Conformity</NAME>
                <DEFINITION>System behavior according to the user expectation</DEFINITION>
           <VALUETYPE>List</VALUETYPE>
              <TENDENCY>lower</TENDENCY>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID=”T6”>
        <NAME>Customization</NAME>
        <DEFINITION>Degree system can be adjusted to ones needs</DEFINITION>
     <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID=”T7”>
        <NAME>Data Access</NAME>
        <DEFINITION>How the data is accessible and how it is protected against access from unauthorized third parties</DEFINITION>
        <VALUETYPE>Range</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID=”T8”>
        <NAME>Data Loss</NAME>
        <DEFINITION>Fear that data moved to the cloud might be lost</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
```

```xml
    <FACTOR FACTORID=”T9”>
      <NAME>Elastic Resourcing</NAME>
      <DEFINITION>Adjustability of resources to match demand and handle spikes</DEFINITION>
      <VALUETYPE>List</VALUETYPE>
      <TENDENCY>higher</TENDENCY>
      <SUBFACTORS>
        <FACTOR FACTORID=”T9_1”>
          <NAME>Bandwidth Elasticity</NAME>
          <DEFINITION>Elasticity of the available network bandwidth</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T9_2”>
          <NAME>CPU Power Elasticity</NAME>
          <DEFINITION>Elasticity of the available processing power</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T9_3”>
          <NAME>Memory Elasticity</NAME>
          <DEFINITION>Elasticity of the available memory</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T9_4”>
          <NAME>Number of VMs Elasticity</NAME>
          <DEFINITION>Elasticity of the virtual machines available</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T9_5”>
          <NAME>Storage Elasticity</NAME>
        <DEFINITION>Elasticity of the storage available</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
      </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID=”T10”>
      <NAME>Fault Tolerance</NAME>
      <DEFINITION>How tolerant the system is to faults</DEFINITION>
      <VALUETYPE>List</VALUETYPE>
      <TENDENCY>higher</TENDENCY>
      <SUBFACTORS>
        <FACTOR FACTORID=”T10_1”>
          <NAME>Reactive</NAME>
          <DEFINITION>Mechanisms to reduce the effects of faults after they occur</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T10_2”>
          <NAME>Proactive</NAME>
          <DEFINITION>Mechanisms to reduce the likelihood that errors do occur</DEFINITION>
          <VALUETYPE>List</VALUETYPE>
          <TENDENCY>higher</TENDENCY>
        </FACTOR>
      </SUBFACTORS>
    </FACTOR>
```

```
<FACTOR FACTORID=”T11”>
    <NAME>Functionality</NAME>
    <DEFINITION>The functionalities a cloud solution provides, compared to a legacy system</DEFINITION>
    <VALUETYPE>List</VALUETYPE>
    <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T12”>
    <NAME>Initial Migration and Data Transfer</NAME>
    <DEFINITION>The time and efforts required for first moving towards a cloudbased solution</DEFINITION>
    <VALUETYPE>Numeric</VALUETYPE>
    <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T13”>
    <NAME>Integration</NAME>
    <DEFINITION>The extent to which a cloudbased can be integrated with existing systems and other cloudbased solutions</DEFINITION>
    <VALUETYPE>List</VALUETYPE>
    <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T14”>
    <NAME>Interoperability</NAME>
    <DEFINITION>The extent cloud systems can communicate with each other and traditional applications</DEFINITION>
    <VALUETYPE>List</VALUETYPE>
    <TENDENCY>higher</TENDENCY>
    <SUBFACTORS>
        <FACTOR FACTORID=”T14_1”>
            <NAME>Storage Interoperability</NAME>
            <DEFINITION>The degree on which information data can be shared between and interpreted by different systems</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T14_2”>
            <NAME>Application Interoperability</NAME>
            <DEFINITION>The degree to which applications can exchange information.</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID=”T14_3”>
            <NAME>OS Interoperability</NAME>
            <DEFINITION>The degree on which different operating systems can communicate and understand each other</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
    </SUBFACTORS>
</FACTOR>
<FACTOR FACTORID=”T15”>
    <NAME>Management and Maintenance of Identity Platform</NAME>
    <DEFINITION>Quality of the platform that allows to add, remove and edit users</DEFINITION>
    <VALUETYPE>List</VALUETYPE>
    <TENDENCY>higher</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T16”>
    <NAME>Management of Authentication Platform</NAME>
    <DEFINITION>Quality of the platform that ensures that entities are who they claim to be</DEFINITION>
    <VALUETYPE>List</VALUETYPE>
    <TENDENCY>higher</TENDENCY>
</FACTOR>
```

```
<FACTOR FACTORID=”T17”>
   <NAME>Network Quality</NAME>
   <DEFINITION>Quality of the network that connects the cloud consumer to the cloud provider</DEFINITION>
   <VALUETYPE>List</VALUETYPE>
   <TENDENCY>lower</TENDENCY>
   <SUBFACTORS>
      <FACTOR FACTORID=”T17_1”>
         <NAME>Bandwidth</NAME>
         <DEFINITION>Bandwidth is the capacity of the network between the consumer and the cloud, measured in bits per second</DEFINITION>
         <VALUETYPE>Numeric</VALUETYPE>
         <TENDENCY>lower</TENDENCY>
      </FACTOR>
      <FACTOR FACTORID=”T17_2”>
         <NAME>Connectivity</NAME>
         <DEFINITION>The time the network link between the consumer and user is available</DEFINITION>
         <VALUETYPE>Range</VALUETYPE>
         <TENDENCY>lower</TENDENCY>
      </FACTOR>
      <FACTOR FACTORID=”T17_3”>
         <NAME>Latency</NAME>
         <DEFINITION>Time it takes a request to reach the destination</DEFINITION>
         <VALUETYPE>Numeric</VALUETYPE>
         <TENDENCY>higher</TENDENCY>
      </FACTOR>
      <FACTOR FACTORID=”T17_4”>
         <NAME>Jitter</NAME>
         <DEFINITION>The variance in latency</DEFINITION>
         <VALUETYPE>Range</VALUETYPE>
         <TENDENCY>higher</TENDENCY>
      </FACTOR>
   </SUBFACTORS>
</FACTOR>
<FACTOR FACTORID=”T18”>
   <NAME>Portability</NAME>
   <DEFINITION>The possibility to use and move components or systems in different environments</DEFINITION>
   <VALUETYPE>List</VALUETYPE>
   <TENDENCY>higher</TENDENCY>
   <SUBFACTORS>
      <FACTOR FACTORID=”T18_1”>
         <NAME>Data Portability</NAME>
         <DEFINITION>Data portability in the context of CC refers to the possibility to move data from one CSP to another</DEFINITION>
         <VALUETYPE>List</VALUETYPE>
         <TENDENCY>higher</TENDENCY>
      </FACTOR>
      <FACTOR FACTORID=”T18_2”>
         <NAME>Service Portability</NAME>
         <DEFINITION>Service portability refers to the possibility to migrate a service from one CSP to another</DEFINITION>
         <VALUETYPE>List</VALUETYPE>
         <TENDENCY>higher</TENDENCY>
      </FACTOR>
      <FACTOR FACTORID=”T18_3”>
         <NAME>Functional Portability</NAME>
         <DEFINITION>Functional portability is similar to service portability, but about migrating functional behavior</DEFINITION>
         <VALUETYPE>List</VALUETYPE>
```

```xml
      <TENDENCY>higher</TENDENCY>
    </FACTOR>
  </SUBFACTORS>
</FACTOR>
<FACTOR FACTORID="T19">
  <NAME>Privacy</NAME>
  <DEFINITION>Includes any concerns cloud consumer might have regarding privacy issues within cloud deployment models</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID="T20">
  <NAME>Quality of Service</NAME>
  <DEFINITION>Level of performance, reliability and availability of the service</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID="T21">
  <NAME>Reliability</NAME>
  <DEFINITION>Probability a system will function as expected over a period of time</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>higher</TENDENCY>
</FACTOR>
<FACTOR FACTORID="T22">
  <NAME>Disaster Recovery</NAME>
  <DEFINITION>How fast a system is expected to be back up after an outtake</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>higher</TENDENCY>
</FACTOR>
<FACTOR FACTORID="T23">
  <NAME>Scalability</NAME>
  <DEFINITION>Scalability is the ability of a system to adjust to the load required</DEFINITION>
  <VALUETYPE>Numeric</VALUETYPE>
  <TENDENCY>higher</TENDENCY>
  <SUBFACTORS>
    <FACTOR FACTORID="T23_1">
      <NAME>Scale Out</NAME>
      <DEFINITION>Scaling out refers to increasing resources of the same type, e.g. increase the numbers VMs to handle more requests</DEFINITION>
      <VALUETYPE>Numeric</VALUETYPE>
      <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="T23_2">
      <NAME>Scale Up</NAME>
      <DEFINITION>Scaling up refers to increase the existing resources and can include physical memory upgrades, CPU speed or network bandwidth upgrades</DEFINITION>
      <VALUETYPE>Numeric</VALUETYPE>
      <TENDENCY>higher</TENDENCY>
    </FACTOR>
  </SUBFACTORS>
</FACTOR>
<FACTOR FACTORID="T24">
  <NAME>Security</NAME>
  <DEFINITION>The perceived security level from the provider</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
  <SUBFACTORS>
```

```
<FACTOR FACTORID=”T24_1”>
  <NAME>Authorization</NAME>
  <DEFINITION>Authorization refers to validating that a user is not only who he claims he is, but also that the identity is authorized to access the requested data</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T24_2”>
  <NAME>Availability</NAME>
  <DEFINITION>The system being accessible by unauthorized user, even in case of recognition of suspicious behavior of different parties </DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T24_3”>
  <NAME>Confidentiality</NAME>
  <DEFINITION>Confidentiality ensures that only authorized entities have access to the protected data</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T24_4”>
  <NAME>Integrity</NAME>
  <DEFINITION>Integrity refers to the fact that data should only be changed by authorized entities</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T24_5”>
  <NAME>MultiTenant Trust</NAME>
  <DEFINITION>Issues arising with multitenancy (shared resources) in cloud computing</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
</SUBFACTORS>
</FACTOR>
<FACTOR FACTORID=”T25”>
  <NAME>Service Response Time</NAME>
  <DEFINITION>The time required from a service to respond to an input</DEFINITION>
  <VALUETYPE>Numeric</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T26”>
  <NAME>Software Assurance</NAME>
  <DEFINITION>The likelihood that the cloud service performs as expected and/or promised in the SLA</DEFINITION>
  <VALUETYPE>Numeric</VALUETYPE>
  <TENDENCY>lower</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T27”>
  <NAME>Standardization</NAME>
  <DEFINITION>The level of interchangeability between different system</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
  <TENDENCY>higher</TENDENCY>
</FACTOR>
<FACTOR FACTORID=”T28”>
  <NAME>Trialability</NAME>
  <DEFINITION>If users receive the option to test a service before committing to it</DEFINITION>
  <VALUETYPE>List</VALUETYPE>
```

```
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID=”T29”>
        <NAME>Usability</NAME>
        <DEFINITION>Usability refers to the experience users have with the cloud service</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
        <SUBFACTORS>
            <FACTOR FACTORID=”T29_1”>
                <NAME>Application Launch Time</NAME>
                <DEFINITION>The time it takes the application be up and running </DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T29_2”>
                <NAME>Installability</NAME>
                <DEFINITION>Refers to how difficult it is to install the service</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>lower</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T29_3”>
                <NAME>Simplicity</NAME>
                <DEFINITION>The difficulty to reach a desired goal</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>lower</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T29_4”>
                <NAME>Learnability</NAME>
                <DEFINITION>Learnability refers to the time and effort required to learn a new system, service or application</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>lower</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID=”T29_5”>
                <NAME>Response Time</NAME>
                <DEFINITION>The time a service requires to show an update to a request of a user</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID=”T31”>
        <NAME>Traceability and Auditability</NAME>
        <DEFINITION>Traceability and auditability refers to the extent the usage and changes of a service and data can be tracked</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID=”T32”>
        <NAME>Utility Based Computing</NAME>
        <DEFINITION>Offering of resources via payasyougo model instead of requiring to buy a system</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID=”T33”>
        <NAME>Vendor LockIn</NAME>
        <DEFINITION>Occurs when customers cannot change the vendor without huge efforts and/or costs</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
```

```xml
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="T34">
            <NAME>Workload Management</NAME>
            <DEFINITION>Workload management is used to distribute work over resources to achieve optimal performance</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
            <SUBFACTORS>
                <FACTOR FACTORID="T34_1">
                    <NAME>Capacity Planning</NAME>
                    <DEFINITION>Planning to ensure that there are enough resources to handle demand</DEFINITION>
                    <VALUETYPE>List</VALUETYPE>
                    <TENDENCY>higher</TENDENCY>
                </FACTOR>
                <FACTOR FACTORID="T34_2">
                    <NAME>Performance Management</NAME>
                    <DEFINITION>Includes tools to monitor and analyze performance metrics</DEFINITION>
                    <VALUETYPE>List</VALUETYPE>
                    <TENDENCY>higher</TENDENCY>
                </FACTOR>
                <FACTOR FACTORID="T34_3">
                    <NAME>Classification</NAME>
                    <DEFINITION>The different classifications of work, e.g. the expected runtime or memory usage of a task</DEFINITION>
                    <VALUETYPE>List</VALUETYPE>
                    <TENDENCY>higher</TENDENCY>
                </FACTOR>
                <FACTOR FACTORID="T34_4">
                    <NAME>Mission Criticality</NAME>
                    <DEFINITION>Workload should be classified into different importances</DEFINITION>
                    <VALUETYPE>List</VALUETYPE>
                    <TENDENCY>higher</TENDENCY>
                </FACTOR>
                <FACTOR FACTORID="T34_5">
                    <NAME>Configuration Management</NAME>
                    <DEFINITION>Enables the identification and control over assets</DEFINITION>
                    <VALUETYPE>List</VALUETYPE>
                    <TENDENCY>higher</TENDENCY>
                </FACTOR>
            </SUBFACTORS>
        </FACTOR>
        <FACTOR FACTORID="T35">
            <NAME>Workload Utilization Ratio</NAME>
            <DEFINITION>The degree resources are used</DEFINITION>
            <VALUETYPE>Numeric</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>

    </FACTORS>

    <FACTORS CATEGORY="Economical">
        <FACTOR FACTORID="E1">
            <NAME>Billing and Metering of Resource Usage</NAME>
            <DEFINITION>The way the resource usage is metered and billed, e.g. how exact it is</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E2">
            <NAME>CAPEX</NAME>
```

```xml
      <DEFINITION>Costs associated with long term investments</DEFINITION>
      <VALUETYPE>List</VALUETYPE>
      <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="E3">
      <NAME>Carbon Footprint</NAME>
      <DEFINITION>The extent to which organizations affect the environment.</DEFINITION>
      <VALUETYPE>List</VALUETYPE>
      <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="E4">
      <NAME>Cost Flexibility</NAME>
      <DEFINITION>How elastic costs are, i.e. to what extent cost vary with the demand of the costumer</DEFINITION>
      <VALUETYPE>List</VALUETYPE>
      <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="E5">
      <NAME>Cost</NAME>
      <DEFINITION>All monetary spendings that are influenced by cloud computing</DEFINITION>
      <VALUETYPE>Numeric</VALUETYPE>
      <TENDENCY>lower</TENDENCY>
      <SUBFACTORS>
        <FACTOR FACTORID="E5_1">
          <NAME>License</NAME>
          <DEFINITION>All the cost associated with licenses</DEFINITION>
          <VALUETYPE>Numeric</VALUETYPE>
          <TENDENCY>lower</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E5_2">
          <NAME>Maintenance</NAME>
          <DEFINITION>Costs that are costs associated with keeping the infrastructure running</DEFINITION>
          <VALUETYPE>Numeric</VALUETYPE>
          <TENDENCY>lower</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E5_3">
          <NAME>Backup</NAME>
          <DEFINITION>Costs associated with backups</DEFINITION>
          <VALUETYPE>Numeric</VALUETYPE>
          <TENDENCY>na</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E5_4">
          <NAME>Energy</NAME>
          <DEFINITION>Costs for energy required to run an IT infrastructure</DEFINITION>
          <VALUETYPE>Numeric</VALUETYPE>
          <TENDENCY>lower</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E5_5">
          <NAME>Hardware</NAME>
          <DEFINITION>All costs associated with (IT)hardware</DEFINITION>
          <VALUETYPE>Numeric</VALUETYPE>
          <TENDENCY>lower</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E5_6">
          <NAME>Migration</NAME>
          <DEFINITION>Migration towards CC will require initial monetary investments, e.g. to acquire new knowledge or data transmission</DEFINITION>
```

```
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="E5_7">
                <NAME>Performance</NAME>
                <DEFINITION>The costs considered for performance therefore includes costs associated with the level of functionality, service response time, accuracy</DEFINITION>
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="E5_8">
                <NAME>Future Requirements</NAME>
                <DEFINITION>Costs which can occur in the future, if their requirements change.</DEFINITION>
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="E5_9">
                <NAME>Data Loss</NAME>
                <DEFINITION>Costs that occur in case of data loss</DEFINITION>
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="E5_10">
                <NAME>Switching Providers</NAME>
                <DEFINITION>Costs associated with switching from one cloud provider to another</DEFINITION>
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="E5_11">
                <NAME>Integration</NAME>
                <DEFINITION>Integration costs includes all monetary spendings associated with integrating the cloud with existing systems and processes</DEFINITION>
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="E5_12">
                <NAME>System Administration</NAME>
                <DEFINITION>Costs associated with administration and maintenance of the ITinfrastructure </DEFINITION>
                <VALUETYPE>Numeric</VALUETYPE>
                <TENDENCY>lower</TENDENCY>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID="E6">
        <NAME>Economies of Scale</NAME>
        <DEFINITION>Economy of scale refers to cost benefits due to the size of an organization</DEFINITION>
        <VALUETYPE>Numeric</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="E7">
        <NAME>Marginal Cost and Profit</NAME>
        <DEFINITION>Marginal costs are the costs for an additional unit and marginal profit the profit for an additional unit</DEFINITION>
        <VALUETYPE>Numeric</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="E8">
        <NAME>Migration Time</NAME>
```

```
            <DEFINITION>The time required for migrating from the existing solution to a cloud solution</DEFINITION>
            <VALUETYPE>Numeric</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E9">
            <NAME>OPEX</NAME>
            <DEFINITION>Includes all the costs required for operating a business</DEFINITION>
            <VALUETYPE>Numeric</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
            <SUBFACTORS>
                <FACTOR FACTORID="E9_1">
                    <NAME>Fixed Costs</NAME>
                    <DEFINITION>Costs incurred independently of the number of users or the resources required</DEFINITION>
                    <VALUETYPE>Numeric</VALUETYPE>
                    <TENDENCY>lower</TENDENCY>
                </FACTOR>
                <FACTOR FACTORID="E9_2">
                    <NAME>Variable Costs</NAME>
                    <DEFINITION>Costs that depend on the output produced or the usage of a service</DEFINITION>
                    <VALUETYPE>Numeric</VALUETYPE>
                    <TENDENCY>higher</TENDENCY>
                </FACTOR>
            </SUBFACTORS>
        </FACTOR>
        <FACTOR FACTORID="E10">
            <NAME>Return on Investment</NAME>
            <DEFINITION>The ratio of the benefit of the investment against the cost of the investment</DEFINITION>
            <VALUETYPE>Numeric</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="E11">
            <NAME>Total Cost of Ownership</NAME>
            <DEFINITION>The total cost of ownership is a financial estimate that includes the total cost of purchasing/subscribing to and running a service or product</DEFINITION>
            <VALUETYPE>Numeric</VALUETYPE>
            <TENDENCY>na</TENDENCY>
        </FACTOR>
    </FACTORS>

    <FACTORS CATEGORY="Organizational">
        <FACTOR FACTORID="O1">
            <NAME>Business Flexibility and Agility</NAME>
            <DEFINITION>How easy an organization can adjust to changes in the environment</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
        </FACTOR>
        <FACTOR FACTORID="O2">
            <NAME>Collaboration</NAME>
            <DEFINITION>The process of working together to achieve a common goal</DEFINITION>
            <VALUETYPE>List</VALUETYPE>
            <TENDENCY>higher</TENDENCY>
            <SUBFACTORS>
                <FACTOR FACTORID="O2_1">
                    <NAME>IntraCompany</NAME>
                    <DEFINITION>Intracompany collaboration refers to all collaboration which is within the same organization, e.g. between different sections of an organization</DEFINITION>
```

```xml
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="O2_2">
                <NAME>InterCompany</NAME>
                <DEFINITION>Intercompany collaboration refers to collaboration
                    between different organizations</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID="O3">
        <NAME>Control</NAME>
        <DEFINITION>Control refers to the authority over an organization and its
            processes</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O4">
        <NAME>Legal and Regulative Compliance</NAME>
        <DEFINITION>The effort required for an organization to comply with the
            legal and regulative environment</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
        <SUBFACTORS>
            <FACTOR FACTORID="O4_1">
                <NAME>Initial</NAME>
                <DEFINITION>Refers to the effort required to initially reach
                    compliance,includes research, negotiations with CSPs and
                    development of contracts and SLAs</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="O4_2">
                <NAME>Maintaining</NAME>
                <DEFINITION>The effort required for maintaining compliance, after
                    it was initially achieved</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID="O5">
        <NAME>Location</NAME>
        <DEFINITION>The physical position of an organization</DEFINITION
            >
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>na</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O6">
        <NAME>IT Competence of Employees</NAME>
        <DEFINITION>The required IT knowledge and experience of the
            employees</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O7">
        <NAME>IT Infrastructure and Management</NAME>
        <DEFINITION>The influence of the existing IT infrastructure and
            management within an organization</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
        <SUBFACTORS>
            <FACTOR FACTORID="O7_1">
```

```
                <NAME>Rigidness</NAME>
                <DEFINITION>Rigidness refers to likeliness of change within organization</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>lower</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="O7_2">
                <NAME>Management Competence</NAME>
                <DEFINITION>The level of competence of the existing management </DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>lower</TENDENCY>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
    <FACTOR FACTORID="O8">
        <NAME>Openness</NAME>
        <DEFINITION>Openness in an organizational context refers to the companies acceptance of new ideas</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O9">
        <NAME>Organizational Compatibility</NAME>
        <DEFINITION>The degree to which an innovation matches existing values, experiences, and needs</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O10">
        <NAME>Ownership of Data</NAME>
        <DEFINITION>The potential changes in who owns data if it is moved towards the cloud</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>lower</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O11">
        <NAME>Process Redesign</NAME>
        <DEFINITION>Potential changes in the workflow within an organizations</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
    </FACTOR>
    <FACTOR FACTORID="O12">
        <NAME>Size of Organization</NAME>
        <DEFINITION>The size of an organization, measured by number of employees or the value of an organization</DEFINITION>
        <VALUETYPE>Numeric</VALUETYPE>
        <TENDENCY>na</TENDENCY>
    </FACTOR>

    <FACTOR FACTORID="O13">
        <NAME>Relational</NAME>
        <DEFINITION>The amount of competition to an organization</DEFINITION>
        <VALUETYPE>List</VALUETYPE>
        <TENDENCY>higher</TENDENCY>
        <SUBFACTORS>
            <FACTOR FACTORID="R1">
                <NAME>Competition Intensity</NAME>
                <DEFINITION>todo</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="R2">
```

```xml
                <NAME>Contracts and Service Level Agreements</NAME>
                <DEFINITION>Contracts and service level agreements are the agreement between two parties</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="R3">
                <NAME>Skill and Expertise of CSP</NAME>
                <DEFINITION>The competence of the Cloud Service Provider regarding skills and expertise</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="R4">
                <NAME>User and Technical Support of CSP</NAME>
                <DEFINITION>The level and quality of support from the provider</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="R5">
                <NAME>Transparency of CSP</NAME>
                <DEFINITION>Transparency refers to the disclosure of information, such as privacy statements, security policies and availability guarantee</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
            </FACTOR>
            <FACTOR FACTORID="R6">
                <NAME>Trust Towards CSP</NAME>
                <DEFINITION>The expected degree that a provider will treat a costumer fair, reasonable and deliver as expected</DEFINITION>
                <VALUETYPE>List</VALUETYPE>
                <TENDENCY>higher</TENDENCY>
                <SUBFACTORS>
                    <FACTOR FACTORID="R6_1">
                        <NAME>Cognitive</NAME>
                        <DEFINITION>Cognitive trust builds on the perceived delivery from the CSP, i.e. if the provider delivers as promised</DEFINITION>
                        <VALUETYPE>List</VALUETYPE>
                        <TENDENCY>higher</TENDENCY>
                    </FACTOR>
                    <FACTOR FACTORID="R6_2">
                        <NAME>Affective</NAME>
                        <DEFINITION>Affective trust is based on the perception of honest concern and care</DEFINITION>
                        <VALUETYPE>List</VALUETYPE>
                        <TENDENCY>higher</TENDENCY>
                    </FACTOR>
                </SUBFACTORS>
            </FACTOR>
        </SUBFACTORS>
    </FACTOR>
</FACTORS>

<RELATIONS>
  <RELATION RELATIONID="REL1" FACTOR1="O12" FACTOR2="O1"/>
  <RELATION RELATIONID="REL2" FACTOR1="O4" FACTOR2="O1"/>
  <RELATION RELATIONID="REL3" FACTOR1="T2" FACTOR2="O1"/>
  <RELATION RELATIONID="REL4" FACTOR1="T33" FACTOR2="O1"/>
  <RELATION RELATIONID="REL5" FACTOR1="T1" FACTOR2="O1"/>
  <RELATION RELATIONID="REL6" FACTOR1="O7_1" FACTOR2="O1"/>
  <RELATION RELATIONID="REL7" FACTOR1="T32" FACTOR2="O1"/>
```

```
    <RELATION RELATIONID=”REL8” FACTOR1=”T23” FACTOR2=”O1”/>
    <RELATION RELATIONID=”REL9” FACTOR1=”T9” FACTOR2=”T23”/>
    <RELATION RELATIONID=”REL10” FACTOR1=”T20” FACTOR2=”T26”/>
    <RELATION RELATIONID=”REL11” FACTOR1=”R2” FACTOR2=”T20”/>
    <RELATION RELATIONID=”REL12” FACTOR1=”R1” FACTOR2=”T26”/>
    <RELATION RELATIONID=”REL13” FACTOR1=”T4” FACTOR2=”E5_3”/>
    <RELATION RELATIONID=”REL14” FACTOR1=”T4” FACTOR2=”T22”/>
    <RELATION RELATIONID=”REL15” FACTOR1=”T8” FACTOR2=”T22”/>
    <RELATION RELATIONID=”REL16” FACTOR1=”T8” FACTOR2=”E5_9”/>
    <RELATION RELATIONID=”REL17” FACTOR1=”R2” FACTOR2=”E5_3”/>
    <RELATION RELATIONID=”REL18” FACTOR1=”R2” FACTOR2=”T4”/>
    <RELATION RELATIONID=”REL19” FACTOR1=”T4” FACTOR2=”T8”/>
    <RELATION RELATIONID=”REL20” FACTOR1=”T32” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL21” FACTOR1=”E5_1” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL22” FACTOR1=”E5_5” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL23” FACTOR1=”E5_3” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL24” FACTOR1=”E5_6” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL25” FACTOR1=”E5_8” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL26” FACTOR1=”E5_10” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL27” FACTOR1=”E5_11” FACTOR2=”E2”/>
    <RELATION RELATIONID=”REL30” FACTOR1=”T24_1” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL31” FACTOR1=”O3” FACTOR2=”O2”/>
    <RELATION RELATIONID=”REL32” FACTOR1=”T24_3” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL33” FACTOR1=”T24_4” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL34” FACTOR1=”O4” FACTOR2=”O2_1”/>
    <RELATION RELATIONID=”REL35” FACTOR1=”O8” FACTOR2=”O9”/>
    <RELATION RELATIONID=”REL36” FACTOR1=”O1” FACTOR2=”O9”/>
    <RELATION RELATIONID=”REL37” FACTOR1=”O6” FACTOR2=”O9”/>
    <RELATION RELATIONID=”REL38” FACTOR1=”O7” FACTOR2=”O9”/>
    <RELATION RELATIONID=”REL39” FACTOR1=”O5” FACTOR2=”O4”/>
    <RELATION RELATIONID=”REL40” FACTOR1=”E3” FACTOR2=”O4”/>
    <RELATION RELATIONID=”REL41” FACTOR1=”T31” FACTOR2=”O4”/>
    <RELATION RELATIONID=”REL42” FACTOR1=”T24” FACTOR2=”O4”/>
    <RELATION RELATIONID=”REL43” FACTOR1=”T19” FACTOR2=”O4”/>
    <RELATION RELATIONID=”REL44” FACTOR1=”T19” FACTOR2=”T24”/>
    <RELATION RELATIONID=”REL45” FACTOR1=”T19” FACTOR2=”T31”/>
    <RELATION RELATIONID=”REL46” FACTOR1=”T5” FACTOR2=”T29”/>
    <RELATION RELATIONID=”REL47” FACTOR1=”T26” FACTOR2=”T29”/>
    <RELATION RELATIONID=”REL48” FACTOR1=”R4” FACTOR2=”T29”/>
    <RELATION RELATIONID=”REL49” FACTOR1=”R4” FACTOR2=”T5”/>
    <RELATION RELATIONID=”REL50” FACTOR1=”O10” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL51” FACTOR1=”T24” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL52” FACTOR1=”T15” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL53” FACTOR1=”T16” FACTOR2=”O3”/>
    <RELATION RELATIONID=”REL54” FACTOR1=”T33” FACTOR2=”O3”/>
       <RELATION RELATIONID=”REL55” FACTOR1=”R2” FACTOR2=”O10”/>
       <RELATION RELATIONID=”REL56” FACTOR1=”R2” FACTOR2=”O3”/>
       <RELATION RELATIONID=”REL57” FACTOR1=”T7” FACTOR2=”O3”/>
       <RELATION RELATIONID=”REL58” FACTOR1=”T24” FACTOR2=”T7”/>
      <RELATION RELATIONID=”REL59” FACTOR1=”E1” FACTOR2=”E4”/>
      <RELATION RELATIONID=”REL60” FACTOR1=”T32” FACTOR2=”E4”/>
      <RELATION RELATIONID=”REL62” FACTOR1=”E9” FACTOR2=”E4”/>
      <RELATION RELATIONID=”REL63” FACTOR1=”E5_10” FACTOR2=”T27”
          />
      <RELATION RELATIONID=”REL64” FACTOR1=”O4” FACTOR2=”T27”/>
      <RELATION RELATIONID=”REL65” FACTOR1=”T27” FACTOR2=”T18”/>
      <RELATION RELATIONID=”REL66” FACTOR1=”T18” FACTOR2=”E5_10”
          />
      <RELATION RELATIONID=”REL67” FACTOR1=”T18” FACTOR2=”T33”/>
      <RELATION RELATIONID=”REL68” FACTOR1=”E6” FACTOR2=”E7”/>
      <RELATION RELATIONID=”REL69” FACTOR1=”O12” FACTOR2=”E6”/>
      <RELATION RELATIONID=”REL70” FACTOR1=”T35” FACTOR2=”E7”/>
      <RELATION RELATIONID=”REL71” FACTOR1=”T32” FACTOR2=”E7”/>
      <RELATION RELATIONID=”REL72” FACTOR1=”T17_1” FACTOR2=”T12”
          />
```

```
<RELATION RELATIONID=”REL73” FACTOR1=”T17_2” FACTOR2=”T12”/>
<RELATION RELATIONID=”REL74” FACTOR1=”E5_1” FACTOR2=”T12”/>
<RELATION RELATIONID=”REL75” FACTOR1=”T14” FACTOR2=”E5_1”/>
<RELATION RELATIONID=”REL76” FACTOR1=”T27” FACTOR2=”T14”/>
<RELATION RELATIONID=”REL77” FACTOR1=”O9” FACTOR2=”E8”/>
<RELATION RELATIONID=”REL78” FACTOR1=”O11” FACTOR2=”E8”/>
<RELATION RELATIONID=”REL79” FACTOR1=”T12” FACTOR2=”E5_6”/>
<RELATION RELATIONID=”REL80” FACTOR1=”E8” FACTOR2=”E5_1”/>
<RELATION RELATIONID=”REL81” FACTOR1=”E8” FACTOR2=”E5_6”/>
<RELATION RELATIONID=”REL82” FACTOR1=”O9” FACTOR2=”O11”/>
<RELATION RELATIONID=”REL83” FACTOR1=”O11” FACTOR2=”E5_1”/>
<RELATION RELATIONID=”REL84” FACTOR1=”R4” FACTOR2=”T12”/>
<RELATION RELATIONID=”REL85” FACTOR1=”R4” FACTOR2=”E5_6”/>
<RELATION RELATIONID=”REL86” FACTOR1=”T12” FACTOR2=”E8”/>
<RELATION RELATIONID=”REL87” FACTOR1=”T5_4” FACTOR2=”T29_3”/>
<RELATION RELATIONID=”REL88” FACTOR1=”E4” FACTOR2=”T29_4”/>
<RELATION RELATIONID=”REL89” FACTOR1=”E4” FACTOR2=”T29_3”/>
<RELATION RELATIONID=”REL90” FACTOR1=”T29_3” FACTOR2=”T5_1”/>
<RELATION RELATIONID=”REL91” FACTOR1=”T6” FACTOR2=”T5_4”/>
<RELATION RELATIONID=”REL92” FACTOR1=”T17_3” FACTOR2=”T29_3”/>
<RELATION RELATIONID=”REL93” FACTOR1=”T25” FACTOR2=”T29_5”/>
<RELATION RELATIONID=”REL94” FACTOR1=”R4” FACTOR2=”T29_4”/>
<RELATION RELATIONID=”REL95” FACTOR1=”R4” FACTOR2=”T5_1”/>
<RELATION RELATIONID=”REL96” FACTOR1=”T5_5” FACTOR2=”T29_3”/>
<RELATION RELATIONID=”REL97” FACTOR1=”T5_5” FACTOR2=”T29_4”/>
<RELATION RELATIONID=”REL98” FACTOR1=”T26” FACTOR2=”R6_1”/>
<RELATION RELATIONID=”REL99” FACTOR1=”R3” FACTOR2=”R6_1”/>
<RELATION RELATIONID=”REL100” FACTOR1=”R5” FACTOR2=”R6_2”/>
<RELATION RELATIONID=”REL101” FACTOR1=”R4” FACTOR2=”R6_2”/>
<RELATION RELATIONID=”REL102” FACTOR1=”R4” FACTOR2=”R6_1”/>
<RELATION RELATIONID=”REL103” FACTOR1=”R3” FACTOR2=”R4”/>
<RELATION RELATIONID=”REL104” FACTOR1=”T28” FACTOR2=”R5”/>
<RELATION RELATIONID=”REL105” FACTOR1=”E11” FACTOR2=”E10”/>
<RELATION RELATIONID=”REL106” FACTOR1=”E2” FACTOR2=”E11”/>
<RELATION RELATIONID=”REL107” FACTOR1=”E9” FACTOR2=”E11”/>
<RELATION RELATIONID=”REL108” FACTOR1=”O1” FACTOR2=”E10”/>
<RELATION RELATIONID=”REL109” FACTOR1=”T21” FACTOR2=”T3”/>
<RELATION RELATIONID=”REL110” FACTOR1=”T17_2” FACTOR2=”T3”/>
```

```
        <RELATION RELATIONID="REL111" FACTOR1="T10" FACTOR2="T21"/>
        <RELATION RELATIONID="REL112" FACTOR1="T24_2" FACTOR2="T21"/>
        <RELATION RELATIONID="REL113" FACTOR1="T3" FACTOR2="T20"/>
        <RELATION RELATIONID="REL114" FACTOR1="T9" FACTOR2="T20"/>
        <RELATION RELATIONID="REL115" FACTOR1="T17" FACTOR2="T20"/>
        <RELATION RELATIONID="REL116" FACTOR1="T21" FACTOR2="T20"/>
        <RELATION RELATIONID="REL117" FACTOR1="T23" FACTOR2="T20"/>
        <RELATION RELATIONID="REL118" FACTOR1="T25" FACTOR2="T20"/>
        <RELATION RELATIONID="REL119" FACTOR1="E5_7" FACTOR2="T3"/>
        <RELATION RELATIONID="REL120" FACTOR1="E5_7" FACTOR2="T9"/>
        <RELATION RELATIONID="REL121" FACTOR1="E5_7" FACTOR2="T20"/>
        <RELATION RELATIONID="REL122" FACTOR1="E5_7" FACTOR2="T21"/>
        <RELATION RELATIONID="REL123" FACTOR1="E5_7" FACTOR2="T25"/>
        <RELATION RELATIONID="REL124" FACTOR1="R2" FACTOR2="E5_7"/>
        <RELATION RELATIONID="REL125" FACTOR1="T32" FACTOR2="E9"/>
        <RELATION RELATIONID="REL126" FACTOR1="E5_12" FACTOR2="E9"/>
        <RELATION RELATIONID="REL127" FACTOR1="E5_1" FACTOR2="T9_1"/>
        <RELATION RELATIONID="REL128" FACTOR1="E5_2" FACTOR2="E9"/>
        <RELATION RELATIONID="REL129" FACTOR1="T4" FACTOR2="E9_2"/>
        <RELATION RELATIONID="REL130" FACTOR1="E5_4" FACTOR2="E9"/>
        <RELATION RELATIONID="REL131" FACTOR1="E5_7" FACTOR2="E9"/>
    </RELATIONS>
</TAXONOMY>
```

References

[1] M. Alhamad, T. Dillon, and E. Chang. Conceptual SLA Framework For Cloud Computing. *4th IEEE International Conference on Digital Ecosystems and Technologies (DEST 2010)*, pages 606–610, Dubai, United Arab Emirates, 2010.

[2] I. E. Allen and C. A. Seaman. Likert Scales And Data Analysis. *Quality Progress*, 40(7):64, 2007.

[3] R. Alnemr, S. Pearson, R. Leenes, and R. Mhungu. COAT: Cloud Offerings Advisory Tool. *IEEE 6th International Conference on Cloud Computing Technology and Science (CloudCom 2014)*, pages 95–100, Singapore, 2014.

[4] M. A. Alsudiari and T. Vasista. Cloud Computing and Privacy Regulations: An Exploratory Study on Issues and Implications. *Advanced Computing: An International Journal (ACIJ)*, 3(2):159–169, 2012.

[5] A. Amato and S. Venticinque. Multi-objective Decision Support for Brokering of Cloud SLA. *IEEE 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA 2013)*, pages 1241–1246, Barcelona, Spain, 2013.

[6] D. Amyot, S. Ghanavati, J. Horkoff, G. Mussbacher, L. Peyton, and E. Yu. Evaluating Goal Models Within the Goal-oriented Requirement Language. *International Journal of Intelligent Systems*, 25(8):841–877, 2010.

[7] M. Armburst, A. Fox, R. Griffith, J. D. Anthony, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, and M. Zaharia. A View of Cloud Computing. *Communications of the ACM*, 53(4):50–58, April 2010.

[8] A. I. Avetisyan, R. Campbell, K. Lai, M. Lyons, D. S. Milojicic, H. Y. Lee, Y. C. Soh, N. K. Ming, J.-Y. Luke, and H. Namgoong. A Global Cloud Computing Testbed. *IEEE Computer*, 43(4):35–43, 2010.

[9] M.-G. Avram. Advantages And Challenges Of Adopting Cloud Computing From An Enterprise Perspective. *Procedia Technol-*

ogy, 12:529–534, 2014.

[10] M. A. Babar and M. A. Chauhan. A Tale of Migration to Cloud Computing for Sharing Experiences and Observations. *2nd ACM International Workshop on Software Engineering for Cloud Computing (ICSE 2011)*, pages 50–56, Waikiki, Honolulu, USA, 2011.

[11] L. Badger, T. Grance, R. Patt-Corner, and J. Voas. Cloud Computing Synopsis and Recommendations. *Computer Security Division, Informational Technology Laboratory, National Institute of Standards and Technology*, 2012.

[12] M. Bedner. *Cloud Computing: Technik, Sicherheit und Rechtliche Gestaltung*. Forum Wirtschaftsrecht. Kassel University Press, 2013.

[13] A. Beloglazov, J. Abawajy, and R. Buyya. Energy-aware Resource Allocation Heuristics for Efficient Management of Data Centers for Cloud Computing. *Future Generation Computer Systems*, 28(5):755–768, 2012.

[14] D. Bernstein, E. Ludvigson, K. Sankar, S. Diamond, and M. Morrow. Blueprint for the Intercloud-protocols and Formats for Cloud Computing Interoperability. *4th IEEE International Conference on Internet and Web Applications and Services (ICIW 2009)*, pages 328–336, Venice, Italy, 2009.

[15] P. V. Beserra, A. Camara, R. Ximenes, A. B. Albuquerque, and N. C. Mendonça. Cloudstep: A Step-by-step Decision Process to Support Legacy Application Migration to the Cloud. *IEEE 6th International Workshop on the Maintenance and Evolution of Service-Oriented and Cloud-Based Systems (MESOCA 2012)*, pages 7–16, Trento, Italy, 2012.

[16] H. P. Borgman, B. Bahli, H. Heier, and F. Schewski. Cloudrise: Exploring Cloud Computing Adoption and Governance With the TOE Framework. *IEEE 46th International Conference on System Sciences (HICSS 2013)*, pages 4425–4435, Hawaii, USA, 2013.

[17] G. Buttarelli. Security and Privacy Regulatory Challenges in the Cloud. *European Cloud Computing Conference*, March Brussels, Belgium, 2012.

[18] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. D. Rose, and R. Buyya. CloudSim: A Toolkit for Modeling and Simulation of Cloud Computing Environments and Evaluation of Resource Provisioning Algorithms. In *Software Practice Experience*, vol-

ume 41, pages 23–50. Wiley Online Library, 2011.

[19] S. Chaisiri, B.-S. Lee, and D. Niyato. Optimization of Resource Provisioning Cost in Cloud Computing. *IEEE Transactions on Services Computing*, 5(2):164–177, April 2012.

[20] H. Chang. Data Protection Regulation and Cloud Computing. In A. S. Cheung and R. H. Weber, editors, *Privacy and Legal Issues in Cloud Computing, Elgar Law, Technology and Society series*, pages 26–42. 2015.

[21] J. Chen, C. Wang, B. B. Zhou, L. Sun, Y. C. Lee, and A. Y. Zomaya. Tradeoffs Between Profit and Customer Satisfaction for Service Provisioning in the Cloud. *ACM 20th International Symposium on High Performance Distributed Computing (HPDC 2011)*, pages 229–238, San Jose, California, USA, 2011.

[22] Cloud Harmony Inc. Cloud Harmony. `https://cloudharmony.com/`, 2016. Last visited in February 2016.

[23] Cloud Standards Customer Council. Interoperability and Portability for Cloud Computing: A Guide. `http://www.cloud-council.org/CSCC-Cloud-Interoperability-and-Portability.pdf`. Last visited November 2015.

[24] R. Cohen. Unified Cloud Interface (UCI). https://code.google.com/p/unifiedcloud/. Last visited July 2015.

[25] M. Convertino, K. M. Baker, J. T. Vogel, C. Lu, B. Suedel, and I. Linkov. Multi-criteria Decision Analysis to Select Metrics for Design and Monitoring of Sustainable Ecosystem Restorations. *Ecological Indicators*, 26:76–86, 2013.

[26] Y.-S. Dai, B. Yang, J. Dongarra, and G. Zhang. Cloud Service Reliability: Modeling and Analysis. *15th IEEE Pacific Rim International Symposium on Dependable Computing (PRDC 2009)*, pages 1–17, Shanghai, China, 2009.

[27] Y. Demchenko, C. Ngo, R. Strijkers, and C. De Laat. Defining Inter-cloud Architecture For Interoperability And Integration. *3rd Citeseer International Conference on Cloud Computing, GRIDs, and Virtualization (CLOUD COMPUTING 2012)*, Nice, France, 2012.

[28] Distributed Management Task Force Inc. Open Virtualization Format. https://www.dmtf.org/standards/ovf. Last visited in February 2016.

[29] D. Ergu, G. Kou, Y. Peng, Y. Shi, and Y. Shi. The Analytic Hierarchy Process: Task Scheduling and Resource Allocation in Cloud Computing Environment. *The Journal of Supercomputing*, 64(3):835–848, 2013.

[30] T. Erl. Service-Oriented Architecture (SOA) Concepts, Technology and Design. 2005.

[31] Ernst & Young. Identity And Access Management - Beyond Compliance. http://www.ey.com/Publication/vwLUAssets/Identity_and_access_management_-_Beyond_compliance/$FILE/Identity_and_access_management_Beyond_compliance_AU1638.pdf. Last visited February 2016.

[32] European Commission. 2000/520/EC: Commission Decision of 26 July 2000 pursuant to Directive 95/46/EC of the European Parliament and of the Council on the Adequacy of the Protection Provided by the Safe Harbour Privacy Principles and Related Frequently Asked Questions Issued by the US Department of Commerce). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000D0520:EN:HTML, Last visited in October 2015.

[33] European Commission. EU Commission and United States Agree On New Framework For Transatlantic Data Dlows: EU-US Privacy Shield. http://europa.eu/rapid/press-release_IP-16-216_en.htm, Last visited in February 2016.

[34] European Parliament, Council of the European Union. Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the Protection of Individuals with Regard to the Processing of Personal Data and on the Free Movement of such Data. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:31995L0046, Last visited in October 2015.

[35] European Parliament, Council of the European Union. Proposal for Regulation of the European Parliament and of the Council on the Protection of Individuals with Regard to the Processing of Personal Data and on the Free Movement of Such Data (General Data Protection Regulation), January 2012. http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52012PC0011, Last visited in October 2015.

[36] European Union. Consolidated Version of the Treaty on the Functioning of the European Union. *Official Journal of the European Union*, 55, October 2012.

[37] European Union Court of Justice. Judgment of the Court - 6 October 2015 Schrems Case C-362/14. `http://curia.europa.eu/juris/celex.jsf?celex=62014CJ0362&lang1=en&type=TXT&ancre=`, Last visited in October 2015.

[38] A. Fox, R. Griffith, A. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, and I. Stoica. Above The Clouds: A Berkeley View Of Cloud Computing. *Deptartment Electrical Engineering and Computer Sciences, University of California, Berkeley, Rep. UCB/EECS*, 28(13):2009, 2009.

[39] R. Garg, M. Heimgartner, and B. Stiller. Decision Support System for Adoption of Cloud-based Services. *6th ACM International Conference on Cloud Computing and Services Science (CLOSER 2016)*, pages 87–94, Rome, Italy, April 2016.

[40] R. Garg, B. Naudts, S. Verbrugge, and B. Stiller. Modeling Legal and Regulative Requirements for Ranking Alternatives of Cloud-based Services (RELAW 2015). *IEEE 8th International Workshop on Requirements Engineering and Law*, pages 25–32, Ottawa, Canada, September 2015.

[41] R. Garg, C. Schmitt, and B. Stiller. Investigating Regulative Implications for User-generated Content and a Design Proposal. *PIK-Praxis der Informationsverarbeitung und Kommunikation*, 37(1):3–13, 2014.

[42] R. Garg and B. Stiller. Design and Evaluation of an Impact Analysis Methodology for the Adoption of Cloud-based Services (IAMCIS). *IEEE 10th International Conference on Network and Service Management (CNSM 2014)*, pages 260–263, Rio de Janerio, Brazil, November 2014.

[43] R. Garg and B. Stiller. Trade-off-based Adoption Methodology for Cloud-Based Infrastructures and Services. *8th International Conference on Autonomous Infrastructure, Management and Security (AIMS 2014), Monitoring and Securing Virtualized Networks and Services*, pages 1–14, Brno, Czech Republic, 2014.

[44] R. Garg and B. Stiller. Evaluation of Influencing Factors in Impact Analysis Methodology for the Adoption of Cloud-based Services. *IEEE 8th International Conference on Cloud Computing*

(CLOUD 2015), pages 999–1002, NewYork, U.S.A, June 2015.

[45] R. Garg and B. Stiller. Factors Affecting Cloud Adoption and Their Interrelations. *5th International Conference on Cloud Computing and Services Science (CLOSER 2015), SCITEPRESS (Science and Technology Publications, Lda.)*, pages 87–94, Lisbon, Portugal, May, 2015.

[46] S. K. Garg, S. Versteeg, and R. Buyya. A Framework for Ranking of Cloud Computing Services. *Future Generation Computer Systems*, 29(4):1012–1023, 2013.

[47] G. Garrison, S. Kim, and R. L. Wakefield. Success Factors for Deploying Cloud Computing. *Communications of the ACM*, 55(9):62–68, 2012.

[48] F. Gravetter and L.-A. Forzano. *Research Methods for the Behavioral Sciences*. Cengage Learning, 2015.

[49] P. Gupta, A. Seetharaman, and J. R. Raj. The Usage And Adoption Of Cloud Computing By Small And Medium Businesses. *International Journal of Information Management*, 33(5):861–874, 2013.

[50] B. Han, V. Gopalakrishnan, L. Ji, and S. Lee. Network Function Virtualization: Challenges and Opportunities for Innovations. *IEEE Communications Magazine*, 53(2):90–97, 2015.

[51] F. Hartwich. Weighting Of Agricultural Research Results: Strength And Limitations Of The Analytic Hierarchy Process (AHP). *Research in Development Economic and Policy, Discussion Paper No. 09/99, Universitat Hohenheim*, 1999.

[52] Harvard Business Review Analytic Services. The Evolution of Decision Making: How Leading Organizations Are Adopting a Data-Driven Culture. `https://hbr.org/resources/pdfs/tools/17568_HBR_SAS%20Report_webview.pdf`, 2012.

[53] J. N. Hoover. Compliance in the Ether: Cloud Computing, Data Security and Business Regulation. *Journal of Business & Technology Law*, 8(1):255–273, 2013.

[54] C. Horne. Understanding Full Virtualization, Paravirtualization, and Hardware Assist. *White paper, VMware Inc*, 2007.

[55] C. L. Hwang and K. Yoon. *Methods for Multiple Attribute Decision Making*. Springer, 1981.

[56] International Telecommunications Union. Privacy in Cloud Computing ITU-T Technology Watch Report. http://www.itu.int/dms_pub/itu-t/oth/23/01/T23010000160001PDFE.pdf, March, 2012.

[57] International Telecommunications Union, Recommendation Z.151 (09/08). https://www.itu.int/rec/T-REC-Z.151-201210-I/en, October, 2012.

[58] A. Ishizaka and P. Nemery. *Multi-criteria Decision Analysis: Methods and Software*. John Wiley and Sons, 2013.

[59] M. B. Javanbarg, C. Scawthorn, J. Kiyono, and B. Shahbodaghkhan. Fuzzy AHP-based Multicriteria Decision Making Systems Using Particle Swarm Optimization. *Expert Systems with Applications*, 39(1):960–966, 2012.

[60] Y. Ju, A. Wang, and X. Liu. Evaluating Emergency Response Capacity by Fuzzy AHP and 2-tuple Fuzzy Linguistic Approach. *Expert Systems with Applications*, 39(8):6972–6981, 2012.

[61] E. E. Kalmar, A. Kertesz, S. Varadi, R. Garg, and B. Stiller. Legal and Regulative Aspects of IoT Cloud Systems. pages 1–7, Vienna, Austria, August 2016.

[62] B. Kandukuri, V. Paturi, and A. Rakshit. Cloud Security Issues. *6th IEEE International Conference on Services Computing (SCC 2009)*, pages 517–520, Bangalore, India September, 2009.

[63] T. Kaya and C. Kahraman. Multicriteria Decision Making In Energy Planning Using A Modified Fuzzy TOPSIS Methodology. *Expert Systems with Applications*, 38(6):6577–6585, 2011.

[64] J. Kerr and K. Teng. Cloud Computing: Legal and Privacy Issues. *12th Annual Academy of Business Disciplines Conference (IABD 2010)*, pages 1–11, Ft. Myers Beach, Florida, USA, 2010.

[65] A. Kertesz and S. Varadi. Legal aspects of data protection in cloud federations. *Security, Privacy and Trust in Cloud Systems*, pages 433–455, 2014.

[66] N. Khan and A. Al-Yasiri. Framework for Cloud Computing Adoption: A Road Map for SMEs to Cloud Migration. *International Journal on Cloud Computing: Services and Architecture (IJCCSA)*, 5(5/6), 2015.

[67] M. Klein, D. Fensel, F. Van Harmelen, and I. Horrocks. The Relation Between Ontologies and XML Schemas. *Electronic Trans.*

on Artificial Intelligence, pages 128–145, 2001.

[68] R. A. Krohling and A. G. Pacheco. A-TOPSIS–An Approach Based on TOPSIS for Ranking Evolutionary Algorithms. *Procedia Computer Science*, 55:308–317, 2015.

[69] T. Laszewski and P. Nauduri. *Migration to the Cloud- Oracle Client/Server Modernization.* Syngress, Elsevier, 2012.

[70] M. Li, S. Yu, Y. Zheng, K. Ren, and W. Lou. Scalable and Secure Sharing of Personal Health Records in Cloud Computing using Attribute-based Encryption. *IEEE Transactions on Parallel and Distributed Systems*, 24(1):131–143, 2013.

[71] X. Li, Y. Li, T. Liu, J. Qiu, and F. Wang. The Method and Tool of Cost Analysis for Cloud Computing. *IEEE International Conference on Cloud Computing*, pages 93–100, Banglore, India September, 2009.

[72] J.-W. Lian, D. C. Yen, and Y.-T. Wang. An Exploratory Study To Understand The Critical Factors Affecting The Decision To Adopt Cloud Computing In Taiwan Hospital. *International Journal of Information Management*, 34(1):28–36, 2014.

[73] R. Likert. A Technique for the Measurement of Attitudes. *Archives of Psychology*, 22(140), 1932.

[74] C. Low, Y. Chen, and M. Wu. Understanding the Determinants of Cloud Computing Adoption. *Industrial Management and Data Systems*, 111(7):1006–1023, 2011.

[75] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, and A. Ghalsasi. *Decision Support Systems*, 51(1):176–189, 2011.

[76] D. Martin, M. Paolucci, S. McIlraith, M. Burstein, D. McDermott, D. McGuinness, B. Parsia, T. Payne, M. Sabou, M. Solanki, et al. Bringing Semantics to Web Services: The OWL-S Approach. *Semantic Web Services and Web Process Composition*, pages 26–42, 2005.

[77] E. Masanet, A. Shehabi, L. Ramakrishnan, J. Liang, X. Ma, B. Walker, V. Hendrix, and P. Mantha. The Energy Efficiency Potential of Cloud-based Software: A U.S. Case Study, Lawrence Berkeley National Laboratory, Berkeley, California. `http://crd.lbl.gov/assets/pubs_presos/ACS/cloud_efficiency_study.pdf`, June, 2013.

[78] É. Masson, M. Berbineau, and S. Lefebvre. Broadband Internet Access on board High Speed Trains, A Technological Survey. *Communication Technologies for Vehicles*, 9006:165–176, 2015.

[79] P. Mell and T. Grance. The NIST Definition of Cloud Computing. *Communications of the ACM*, 53(6):50, 2010.

[80] A. Mendoza. *Utility Computing Technologies, Standards, and Strategies*. Artech House, 2007.

[81] M. Menzel and R. Ranjan. CloudGenius: Decision Support For Web Server Cloud Migration. *ACM 21st International Conference on World Wide Web (WWW 2012)*, pages 979–988, Lyon, France, 2012.

[82] M. Menzel, M. Schönherr, and S. Tai. $(MC^2)^2$: Criteria, Requirements and a Software Prototype for Cloud Infrastructure Decisions. *Software: Practice and Experience*, 43(11):1283–1297, 2013.

[83] J. M. Merigó and A. M. Gil-Lafuente. New Decision-making Techniques And Their Application In The Selection Of Financial Products. *Information Sciences*, 180(11):2085–2094, 2010.

[84] Microsoft. The Economics of the Cloud. `http://news.microsoft.com/download/archived/presskits/cloud/docs/the-economics-of-the-cloud.pdf`, November, 2010.

[85] R. Mijumbi, J. Serrat, J.-L. Gorricho, N. Bouten, F. De Turck, and R. Boutaba. Network Function Virtualization: State-of-the-art and Research Challenges. *IEEE Communications Surveys and Tutorials*, 18(1):236–262, 2015.

[86] S. C. Misra and A. Mondal. *Mathematical and Computer Modelling*, 53(3):504–521, 2011.

[87] L. Morgan and K. Conboy. Factors Affecting The Adoption Of Cloud Computing: An Exploratory Study. *21st European Conference on Information Systems (ECIS 2013)*, pages 1–12, Utrecht, Netherlands, 2013.

[88] J. Mylopoulos, L. Chung, and E. Yu. From Object-oriented To Goal-oriented Requirements Analysis. *Communications of the ACM*, 42(1):31–37, 1999.

[89] B. Naudts, J. Spruytte, J. Van Ooteghem, S. Verbrugge, D. Colle, and M. Pickavet. Internet on Trains: A Multi-criteria Analysis

of On-board Deployment Options for On-train Cellular Connectivity. *16th International Telecommunications Network Strategy and Planning Symposium (Networks 2014)*, pages 1–7, Funchal, Madeira Island, Portugal, 2014.

[90] NetApp. The Journey from Traditional IT to the Cloud-Net App. http://webobjects.cdw.com/webobjects/media/pdf/netapp/NetApp-Virtualization-To-Cloud-Brochure-1.pdf?cm_sp=NAPShowcase-_-Cat4-_-CloudComputing. Last visited January 2015.

[91] O. K. Ngwenyama and N. Bryson. Making The Information Systems Outsourcing Decision: A Transaction Cost Approach To Analyzing Outsourcing Decision Problems. *European Journal of Operational Research*, 115(2):351–367, 1999.

[92] D. Niu, C. Feng, and B. Li. Pricing Cloud Bandwidth Reservations under Demand Uncertainty. *ACM SIGMETRICS Performance Evaluation Review*, 40(1):151–162, 2012.

[93] M. S. Obaidat, A. Anpalagan, and I. Woungang. Green Data Centers. *Handbook of Green Information and Communication Systems*, 2012.

[94] Open Grid Forum. Open Cloud Computing Interface. http://occi-wg.org/. Last visited July 2015.

[95] PaaS Profiles. Platform as a Service Provider Comparison. http://www.paasify.it/vendors, 2016. Last visited in February 2016.

[96] D. Petcu. Portability and Interoperability Between Clouds: Challenges and Case Study. In *Towards a Service-Based Internet*, pages 62–74. Springer, 2011.

[97] J. Petersson. Cloud Metering and Billing. http://www.ibm.com/developerworks/cloud/library/cl-cloudmetering/cl-cloudmetering-pdf.pdf, 2011. Last visited in September 2016.

[98] Pike Research. Cloud Computing to Reduce Global Data Center Energy Expenditures by 38% in 2020. https://www.navigantresearch.com/newsroom/cloud-computing-to-reduce-global-data-center-energyexpenditures-by-38-in-2020, December, 2010.

[99] S. Rajendran. *Organizational Challenges In Cloud Adoption And Enablers Of Cloud Transition Program.* PhD thesis, Massachusetts Institute of Technology, 2013.

[100] T. L. Saaty. Analytic Hierarchy Process. In *Encyclopedia of Operations Research and Management Science*, pages 19–28. Springer, 2001.

[101] T. L. Saaty and L. G. Vargas. *Decision making with the analytic network process.* Springer, 2006.

[102] K. Salah and R. Boutaba. Estimating Service Response Time for Elastic Cloud Applications. *IEEE 1st International Conference on Cloud Networking (CLOUDNET 2012)*, pages 12–16, Paris, France, 2012.

[103] P. Saripalli and G. Pingali. Madmac: Multiple attribute decision methodology for adoption of clouds. *IEEE 4th International Conference on Cloud Computing (CLOUD 2011)*, pages 316–323, Washington DC, USA, 2011.

[104] J. Sen. Security and Privacy Issues in Cloud Computing. *Architectures and Protocols for Secure Information Technology Infrastructures, IGI Global*, pages 1–45, 2013.

[105] J. P. Sluijs, P. Larouche, and W. Sauter. Cloud Computing in the EU Policy Sphere. *Journal of Intellectual Property, Information Technology and e-Commerce Law*, 3(1):12–32, 2011.

[106] M. K. Srinivasan, K. Sarukesi, P. Rodrigues, M. S. Manoj, and P. Revathy. State-of-the-art Cloud Computing Security Taxonomies: A Classification of Security Challenges in the Present Cloud Computing Environment. *ACM International Conference on Advances in Computing, Communications and Informatics*, pages 470–476, Chennai, Madras, India, 2012.

[107] D. N. Staiger. Cross-Border Data Flow in the Cloud between the EU and the US. In A. S. Cheung and R. H. Weber, editors, *Privacy and Legal Issues in Cloud Computing, Elgar Law, Technology and Society Series*, pages 96–117. 2015.

[108] E. Stevens-Navarro and V. W. Wong. Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks. *IEEE 63rd Vehicular Technology Conference (VTC 2006)*, 2:947–951, Melbourne, Australia, 2006.

[109] M. Stieninger, D. Nedbal, W. Wetzlinger, G. Wagner, and M. A. Erskine. Impacts on the Organizational Adoption of Cloud Computing: A Reconceptualization of Influencing Factors. *Procedia Technology*, 16:85–93, 2014.

[110] K. Stravoskoufos, A. Preventis, S. Sotiriadis, and E. G. Petrakis. A Survey on Approaches for Interoperability and Portability of Cloud Computing Services. *4th International Conference on Cloud Computing and Services Science (CLOSER 2013)*, pages 112–117, Barcelona, Spain, 2013.

[111] N. A. Sultan. *International Journal of Information Management*, 31(3):272–278, 2011.

[112] B. Tang, R. Sandhu, and Q. Li. Multi-tenancy Authorization Models for Collaborative Cloud Services. *Concurrency Computation Practice Experience*, 26(11):2851–2868, 2014.

[113] A. Tchana, L. Broto, and D. Hagimont. Fault Tolerant Approaches in Cloud Computing Infrastructures. *8th International Conference on Autonomic and Autonomous Systems (ICAS 2012)*, pages 42–48, St. Maarten, Netherlands Antilles, 2012.

[114] Tech Target. Cloud-based Backup: Best Strategies and Practices. `http://searchdatabackup.techtarget.com/essentialguide/Learn-strategies-best-practices-for-cloud-based-backups`, 2016. Last visited in February 2016.

[115] The OPEN Group. Cloud Computing for Business : What is Cloud? `http://www.opengroup.org/cloud/cloud/cloud_for_business/what.htm`. Last visited February 2016.

[116] The OPEN Group. Cloud Computing Portability and Interoperability. `http://www.opengroup.org/cloud/cloud/cloud_iop/cloud_port.htm`. Last visited February 2016.

[117] L.-I. Tong, C.-H. Wang, and H.-C. Chen. Optimization Of Multiple Responses Using Principal Component Analysis And Technique For Order Preference By Similarity To Ideal Solution. *The International Journal of Advanced Manufacturing Technology*, 27(3-4):407–414, 2005.

[118] V. Tran, J. Keung, A. Liu, and A. Fekete. Application Migration to Cloud: a Taxonomy of Critical Factors. *2nd ACM International Conference on Software Engineering for Cloud Computing (ICSE 2011)*, pages 22–28, Waikiki, Honolulu, USA, 2011.

[119] V. X. Tran, H. Tsuji, and R. Masuda. A New QoS Ontology and Its QoS-based Ranking Algorithm for Web Services. *Simulation Modelling Practice and Theory*, 17(8):1378–1398, 2009.

[120] E. Triantaphyllou. *Multi-criteria Decision Making Methods: A Comparative Study*, volume 44. Springer Science & Business Media, 2013.

[121] G. G. Udo. Using Analytic Hierarchy Process to Analyze the Information Technology Outsourcing Decision. *Industrial Management and Data Systems*, 100(9):421–429, 2000.

[122] University of Ottawa. jUCMNav v6.0.0. http://jucmnav.softwareengineering.ca/ucm/bin/ view/ProjetSEG/WebHome, Last visited in October 2015.

[123] E. Walker. The Real Cost of a CPU Hour. *IEEE Computer*, 42(4):35–41, April 2009.

[124] J. J. Wang and D. L. Yang. Using a Hybrid Multi-criteria Decision Aid Method for Information Systems Outsourcing. *Computers and Operations Research*, 34(12):3691–3700, 2007.

[125] L. Wang, J. Tao, M. Kunze, A. C. Castellanos, D. Kramer, and W. Karl. Scientific Cloud Computing: Early Definition and Experience. *10th IEEE International Conference on High Performance Computing and Communications (HPCC 2008)*, 8:825–830, Dalian, China, 2008.

[126] M. Wang and Y. Liu. QoS Evaluation Of Cloud Service Architecture Based On ANP. *International Symposium on the Analytic Hierarchy Process*, Kuala Lumpur, Malaysia, 2013.

[127] R. H. Weber. Legal Safeguards for Cloud Computing. In A. S. Cheung and R. H. Weber, editors, *Privacy and Legal Issues in Cloud Computing, Elgar Law, Technology and Society Series*, pages 43–68. 2015.

[128] Z. Xiao, W. Song, and Q. Chen. Dynamic Resource Allocation using Virtual Machines for Cloud Computing Environment. *IEEE Transactions on Parallel and Distributed Systems*, 24(4):1107–1117, 2013.

[129] R. Yanosky. From Users To Choosers: The Cloud And The Changing Shape Of Enterprise Authority. *The Tower And The Cloud*, pages 126–136, 2008.

[130] F. Ye and Y. Li. An Extended TOPSIS Model Based on the Possibility Theory under Fuzzy Environment. *Knowledge-Based Systems*, 67:263–269, 2014.

[131] E. O. Yeboah-Boateng and K. A. Essandoh. Factors Influencing the Adoption of Cloud Computing by Small and Medium Enterprises (SMEs) in Developing Economies. *International Journal of Emerging Science and Engineering (IJESE)*, 2(4):13–20, 2014.

[132] R. K. Yin. *Case Study Research: Design and Methods.* Sage publications, 2013.

[133] S. Yu, C. Wang, K. Ren, and W. Lou. Achieving Secure, Scalable, And Fine-grained Data Access Control In Cloud Computing. *IEEE 29th Conference on Computer Communications (INFOCOM 2010)*, pages 1–9, San Diego, California, USA, 2010.

[134] S. Zardari and R. Bahsoon. Cloud Adoption: a Goal-oriented Requirements Engineering Approach. *ACM 2nd International Conference on Software Engineering for Cloud Computing (ICSE 2011)*, pages 29–35, Honolulu, Hawaii, USA, 2011.

[135] W. Zhou, P. Ning, X. Zhang, G. Ammons, R. Wang, and V. Bala. Always Up-to-date: Scalable Offline Patching Of VM Images In A Compute Cloud. *ACM 26th Annual Computer Security Applications Conference (ACSAC 2010)*, pages 377–386, Austin, Texas, USA, 2010.

[136] Zimory GmbH. High Availability In Cloud Computing. `http://www.zimory.com/fileadmin/zimory/Downloads/Whitepaper/ProductHighAvailabilityinCloudComputing-270813-1611-134.pdf`. Last visited February 2016.

[137] D. Zissis and D. Lekkas. Addressing Cloud Computing Security Issues. *Future Generation Computer Systems*, 28(3):583–592, 2012.

List of Figures

List of Tables

Acknowledgments

I am very grateful to a number of people that have helped me, directly or indirectly, through the arduous work that culminates with this thesis.

Firstly, I would like to thank Prof. Dr. Burkhard Stiller for believing in me, allowing me to join the Communication Systems Group (CSG) at the University of Zurich, giving me freedom to research topics that I found interesting, and precious help, feedback, and understanding during several difficult stages. In addition, I would like to thank Prof. Dr. Joan Serrat for being my co-supervisor and inspiring me, as well as providing me with highly valuable feedback. Thank you!

Furthermore, I would like to thank all students that I have supervised while working on this thesis for the rich discussions and contributions.

It has been an immense pleasure working at the CSG and enjoying the true friendship of my work colleagues, including warm discussions about diverse subjects with current colleagues Daniel Dönni, Andri Lareida, Dr. Guilherme Machado, Dr. Corinna Schmitt, Dr. Thomas Bocek, Dr. Christos Tsiaras, Lisa Kristiana and Patrick Poullie, as well as former colleague Dr. Martin Waldburger.

I would like to also thank God, the almighty, for showering his eternal bliss and wisdom. Finally, I would like to thank my parents and husband for the unconditional support for all those years, I love you all!

Curriculum Vitae

RADHIKA GARG WAS BORN on June 25, 1988, in Bhopal, India. In 2010, she has obtained a four-year degree named "Bachelors of Science" in Computer Science from the Mody Institute of Technology and Science (MITS), India.

In early 2011, Radhika Garg moved to Zurich, Switzerland to become a master student of informatik at University of Zurich until early 2013. After getting the degree of Master of Sceince, MSc, with a concentration in software systems, she joined Communication Systems Group (CSG) at the Department of Informatics of the University of Zurich as a doctoral student as well as a research assistant. The work has involved a multitude of tasks, including supervising students and assisting in lectures conducted by CSG. Radhika has also been involved in the following research project - "Management of the Future Internet (FLAMINGO) - wherein her work concentrated on analyzing economic, legal, and regulative constraints in the area of network and service management. Therefore, her thesis was partially funded by FLAMINGO.

Radhika s main research interests are decision analytics primarily involving organizations, legal and regulative constraints of distributed systems, Internet of things, and user-generated data. Her doctoral thesis was supervised by Prof. Dr. Burkhard Stiller (University of Zurich, Switzerland) and Prof. Dr. Joan Serrat-Fernandez (Universitat Politècnica de Catalunya, Barcelona, Spain).